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Quibble Creek Integrated Stormwater Management Plan (ISMP)

Final Report
February 2014
KWL Project No. 471.239-300

Prepared for:

CITY OF SURREY
the future lives here.

Prepared by:

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Executive Summary

Executive Summary

The City of Surrey (City) initiated an Integrated Stormwater Management Plan (ISMP) for Quibble Creek, located in the north part of the City, which drains into the Mud Bay Estuary via Bear Creek and the Serpentine River. The 656 ha study area is largely urbanized with single family residential, high density residential, commercial and industrial land uses. When the plans for re-development of the Quibble Creek watershed are realized, the total impervious area in the watershed is expected to increase by 7%.

Quibble Creek has five tributaries, listed in order from downstream to upstream: T1: Ursus Creek, T2: Bryan Creek, T3: King George Creek, T4: Queen Elizabeth Creek, and T5: Laurel Creek.

ISMP Goals

This report fulfills the goals of the ISMP including:

- Document the existing condition of the drainage system and the ecological health of the watershed;
- Identify enhancement opportunities for aquatic and wildlife habitats;
- Determine how development can proceed with minimal effects on flooding, erosion, water quality and ecological health;
- Identify required remedial and new capital work items; and
- Provide for long-term “Net Gain” in watershed health.

The Quibble Creek Integrated Stormwater Management Plan (ISMP) sets out how the resources within the watershed can be managed to balance land development and stormwater management with environmental protection, watershed health preservation and enhancement of social and environmental values.

Key Issues in Quibble Creek Watershed

During the study process the following key issues were identified in the Quibble Creek Watershed.

Table i: Summary of Key Issues

Key Issues
Flood Management • Undersized storm sewers and culverts
Erosion Management • Erosion in the stream channels
Mitigation of Future Development/Redevelopment Impacts • Increasing imperviousness in the watershed with new development and re-development
Environmental Protection and Enhancement • Threats to Riparian and Stream integrity
Watershed Vision • Need for establishing the long term vision for the watershed

The Integrated Stormwater Management Plan

- The Vision for the watershed was developed through two key workshops with stakeholders. The vision for the Quibble Creek watershed has three pillars:
    - Quibble Creek remains an essential part of the Surrey's developing City Centre, providing access to nature and educational opportunities for people and significant in-steam and riparian habitat for fish and wildlife.
    - The net health of the watershed is protected and maintained or improved over the long-term, through the building and re-development process.
    - The stormwater infrastructure continues to protect life and property from erosion and flooding.
- Stormwater criteria are proposed for all future development and redevelopment:

Capture 32 mm of rainfall (50% of 2-year 24-hour) through a prioritized process of infiltration, evapotranspiration, and detention.

Reduce post-development peak flows to predevelopment values for the 5-year event (in City Centre also detain 2-year and 10-year events).

Treat runoff water quality to achieve TSS of less than 25 mg/L.

Protect riparian areas as per the Riparian Areas Regulation. Provide 30m riparian setbacks along Quibble Creek.

Provide stormwater conveyance as per the City's Design Criteria Manual.

- A capital upgrade plan was developed to address the existing and future conveyance system capacity issues. The total capital costs of the proposed upgrades are estimated at $4.9 million and include:
    - High priority: major culverts, $1.9 million.
    - Medium Priority: minor storm sewer pipes, $270,000.
    - End of Service Life: minor storm sewer pipes, $1.7 million.
    - Future (DCC) Upgrades: major storm sewer pipes, $210,000 and
      Future (DCC) Upgrades: minor storm sewer pipes, $880,000.
- Two high risk erosion sites were identified for immediate action ($400,000 cost allowance). The mitigation of further erosion is to be addressed through volumetric reduction source controls and detention to be applied to all future development and redevelopment.
- Water quality treatment for future development should primarily be accomplished through the application of the on-site volume reduction source controls. For areas that do not have source controls or do not meet the water quality treatment criteria, regional water quality facilities such as oil and grit separators should be considered.
- Apply RAR setbacks throughout the watershed as a minimum and look for opportunities to increase the setbacks to 30m along Quibble Creek during redevelopment. A number of sites have been identified for riparian restoration through reforestation ($180,000) and invasive species management ($25,000/ha).

- Apply RAR setbacks throughout the watershed as a minimum and look for opportunities to increase the setbacks to 30m along Quibble Creek during redevelopment. A number of sites have been identified for riparian restoration through reforestation ($180,000) and invasive species management ($25,000/ha).
- Four park areas totalling 2.2 ha were identified for reforestation in non-riparian areas, both as a means to increase ecological value and to restore hydrological functions provided by tree vegetation and forest soils over the long term.
- A number of potential fish habitat restoration projects (large woody debris and boulder placement and off-channel habitat creation) have been identified to mitigate existing impacts (240,000).
- Two fish passage improvement projects are proposed on Ursus Creek ($120,000) and on the Quibble Creek mainstem ($250,000). Opportunities for improving fish passage at other culvert barriers should be assessed over the long term as part of infrastructure renewal.
- A number of Bylaw and Standards changes are proposed to avoid conflicts with the requirements proposed in this ISMP and with the latest stormwater management methodologies.
- Monitoring of key parameters in the watershed is proposed to comply with the Metro Vancouver Adaptive Management Framework and to assess the long term effectiveness of the ISMP.

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Section 1

Introduction and Framework for Quibble Creek ISMP

1. Introduction and Framework for Quibble Creek ISMP

1.1 Introduction

Quibble Creek is a tributary to Bear Creek, which in turn is a major tributary of the Serpentine River. The Serpentine River discharges to the Pacific Ocean through the Mud Bay Estuary. The study area is shown on Figure 1-1.

Quibble Creek has five tributaries, listed in order from downstream to upstream: T1: Ursus Creek, T2: Bryan Creek, T3: King George Creek, T4: Queen Elizabeth Creek, and T5: Laurel Creek (as shown on Figure 1-1). The 656 ha watershed is largely urbanized with single family residential, high density residential, commercial and industrial land uses. Despite the high level of urbanization, environmental resources, including Coho salmon and Cutthroat trout, are present throughout the creek system. Pressures on these resources are increasing with ongoing development activity and population growth.

Quibble Creek watershed has experienced substantial urban development over the past 50 years. Plans for the future of the area involve redevelopment of a large portion of the watershed as outlined in the City of Surrey's Official Community Plan (OCP) and the Surrey City Centre Neighbourhood Concept Plan (NCP), approximately 51%, into part of a new downtown core known as the Surrey City Centre. In addition, the watershed is expected to experience infilling and some redevelopment of the single family residential neighbourhoods outside the City Centre boundaries. When the plans for re-development of the Quibble Creek watershed are realized, the total impervious area in the watershed is expected to increase by 7%. This appears to be a small increase, but is due to the watershed already being largely built out. The Quibble Creek Integrated Stormwater Management Plan (ISMP) sets out how the resources within the watershed can be managed to balance land development and stormwater management with environmental protection, watershed health preservation and enhancement of social and environmental values. Green spaces, riparian corridors, and economic considerations are integrated into the study to provide a holistic and integrated outlook for the long term health of this watershed.

Quibble Creek ISMP Purpose and Objectives

This report fulfills the goals of the ISMP including:

- Document the existing condition of the drainage system and the ecological health of the watershed;
- Identify enhancement opportunities for aquatic and wildlife habitats;
- Determine how development can proceed with minimal effects on flooding, erosion, water quality and ecological health;
- Identify required remedial and new capital work items; and
- Provide for long-term "Net Gain" in watershed health.

1.2 LWMP Stormwater Commitments

The 2001 Metro Vancouver *Liquid Waste Management Plan* (LWMP) included commitments for stormwater management that incorporated:

- sharing of information and knowledge through the Interagency Liaison Group;
- stakeholder participation;
- updating and adopting policies and bylaws; and
- undertaking watershed-scale Integrated Stormwater Management Plans (ISMPs).

In 2002, Metro Vancouver, SILG members and KWL developed the Terms of Reference Template for ISMPs to provide guidance and a flexible framework to the ISMP planning process. The Template document was updated in 2005 based on feedback from member municipalities on its application.

Metro Vancouver updated the LWMP in 2010 to create the *Integrated Liquid Waste and Resource Management Plan (ILWRMP), May 2010*. The key stormwater points are summarized as follows:

- Continue requirement for ISMP planning and implementation.
- Place emphasis on managing rainwater runoff at the site level which reduces negative quality and quantity impacts.
- Integrate land use planning and stormwater management.
- Improve stormwater bylaws and development of design standards and guidelines.
- Promote the collection and use of rainwater for non-potable water uses.
- Develop watershed health indicators.

The Ministry of Environment's accompanying letter requires the development of a coordinated program to monitor stormwater, and to assess and report the implementation and effectiveness of ISMPs using a weight-of-evidence performance measurement approach. The ISMP completion deadline may be extended from 2014 to 2016.

Metro Vancouver and its members provide progress reports to the province every two years and will review and update the ILWRMP on an eight year cycle.

1.3 Existing Bylaws

City bylaws form part of the context for the ISMP study. Existing bylaws related to stormwater management include:

Stormwater Drainage Regulation and Charges (By-Law #16610) – to regulate extensions, connections, and use of the stormwater drainage system, to impose connection charges to the stormwater drainage system, and to prohibit the fouling, obstructing, or impeding the flow of any stream, creek waterway, watercourse, ditch, or stormwater drainage system.

Erosion and Sedimentation Control (By-Law #16138) – All applications for proposed construction on land areas of 2000 m^2 or larger, shall be submitted with a complete ESC Permit application to the City. All construction on land areas of less than 2000 m^2 shall utilize the best management practices for erosion and sediment control as outlined in Schedule "B" of the By-Law.

Zoning (By-law #12000) – Part 8.D – requires a minimum setback requirement of 15 m from any watercourse.

Subdivision and Land Development (By-Law #8830) – to regulate the subdivision and development of land. It sets out servicing requirements, including drainage works, for new developments and the circumstances under which alternative servicing systems can be implemented. The bylaw also describes the expectations of developers to provide land and facilities for drainage control. Existing Stormwater Criteria

City of Surrey Stormwater Criteria

Table 1-1 summarizes the existing City of Surrey stormwater criteria applicable in the Quibble Creek watershed.

Table 1-1: Summary of Existing Stormwater Criteria

Application		Criteria/Methodology
Hydrotechnical Component (Flood and Erosion Protection)	Minor Drainage System	• 5-year return period design event.
	Major Drainage System	• 100-year return period design event.
	Agricultural Lowland Flooding – ARDSA[1]	• Maintenance of a flood control and drainage system in the lowlands that meets provincial guidelines for agriculture in floodplains
Environmental Component (Environmental Protection)	Watercourse Erosion Prevention	• Control the 5-year post-development flow to 50% of the 2-year post development rate; or • Control the 5-year post-development flow to 5-year pre-development flow rate.

1. ARDSA = Agriculture and Rural Development Subsidiary Agreement. Not applied during this study.

Surrey City Centre Criteria

In the *Surrey City Centre General Land Use Plan Update – Utility Servicing* (AECOM 2010) report Table 7-1, a stormwater strategy and performance targets were summarized for the City Centre area. The strategy concludes that source controls or best management practices (BMPs) are a key element in achieving the objectives and performance targets. Table 1-2 below shows the criteria set in that report.

Table 1-2: Stormwater Strategy and Performance Targets for City Centre Area*

Objective	Strategy	Performance Target
1. Adequately service the area to protect life and property	Ensure the drainage system is designed according to the City of Surrey Engineering Department Design Criteria Manual.	As outlined in the Design Criteria Manual
2. Mitigate the adverse impacts of urban runoff water quality on watercourses	Control the flow of pollutants from the larger sources (construction sites and motor vehicles).	TSS < 25 mg/litre
3. Mitigate the adverse impacts of flows and velocities in the watercourse	Control the volume and rate of flow from frequent rainfall events and ensure sufficient base flows in streams.	Volume: Retain 50% of the 2-year storm Flow Rate: Reduce post-development discharge rate to pre-development discharge rate for the 2, 5 and 10 year 24 hour storm.
4. Protect the riparian habitat and support the aquatic life along the watercourses	Stream corridors are protected by setting minimum stream setbacks.	30 metre riparian corridor (e.g. 30 metre from top of bank on either side of the stream) is protected along the entire length of all watercourses.

**Criteria from Surrey City Centre General Land Use Plan Update – Utility Servicing, Report 2 – Stormwater Best Management Practices Strategy* (AECOM 2010).

1.4 Scope of Work

The work program is summarized in Table 1-2.

Table 1-3: Engineering Work Program

Major Tasks		
Stage 1 - Review Existing Information and Data Collection	1.1	Gather and Review Available Information
	1.2	Project Initiation Meeting
	1.3	Base Map Preparation (GIS database)
	1.4	Engineering Inventory
	1.5	Environmental Inventory and Assessment
	1.6	Hydrologic/Hydraulic Modelling and Existing Land Use Assessment
	1.7	Stakeholder Mail-out and City Meeting #1.
Stage 2 - Vision for Future Development	2.1	Estimated Future Land Use
	2.2	City Meeting #2 to Establish Watershed Goals and Vision for Future Development
	2.2a	Meeting with Outside Architects and City Staff
	2.3	Stakeholder Mail-out and Consultation with Regulatory Agencies
	2.4	Revised Future Land Use, Vision, and Goals
Stage 3 - ISMP - Implementation Plan, Funding Strategies, and Enforcement	3.1	Evaluate BMPs and Recommend Cost Effective Solutions
	3.2	Future Land Use Modelling and Hydrotechnical Assessment
	3.3	Erosion Mitigation Works
	3.4	Environmental Compensation and Enhancement Works
	3.5	Capital Cost Estimates and Funding Strategies
	3.6	Approval Procedure and Enforcement Strategy
	3.7	City Meeting #3 to Present ISMP
Stage 4 - Monitoring & Assessment Plan	4.1	Develop a Monitoring Strategy
	4.2	Adaptive Management
	4.3	Reporting

1.5 Project Team

This project was undertaken by an inter-disciplinary team of professionals. The members and companies involved are outlined in the following table.

Table 1-4: Project Team

Firm	Team Members
City of Surrey	David Hislop, P.Eng., Project Manager, Drainage Planning Carrie Baron, Engineering Mary Beth Rondeau, Senior Planner Gary Gahr, Planning Manager North Stephen Godwin, Engineering Environmental Coordinator Kristen Tiede, Project Engineer, Transportation Preet Heer, Senior Planner Ted Uhrich, Manager, Parks Research and Design Don Luymes, Manager of Community Planning at City of Surrey Pat Lau, Planner Doug Merry, Parks Planning Technician Patrick Klassen, Parks and Recreation Planner
Kerr Wood Leidal Associates Ltd.	Laurel Morgan, M.Sc., P.Eng., Project Manager Chris Johnston, P.Eng., Technical Review David Lee, P.Eng., Project Engineer Aidan Hough, EIT, Modelling Engineer Jack Lau, GIS Specialist Sara Pour, EIT, Junior Stormwater Engineer
Raincoast Applied Ecology, LLC	Nick Page, B.L.A., M.Sc., R.P.Bio., Biologist/Ecologist

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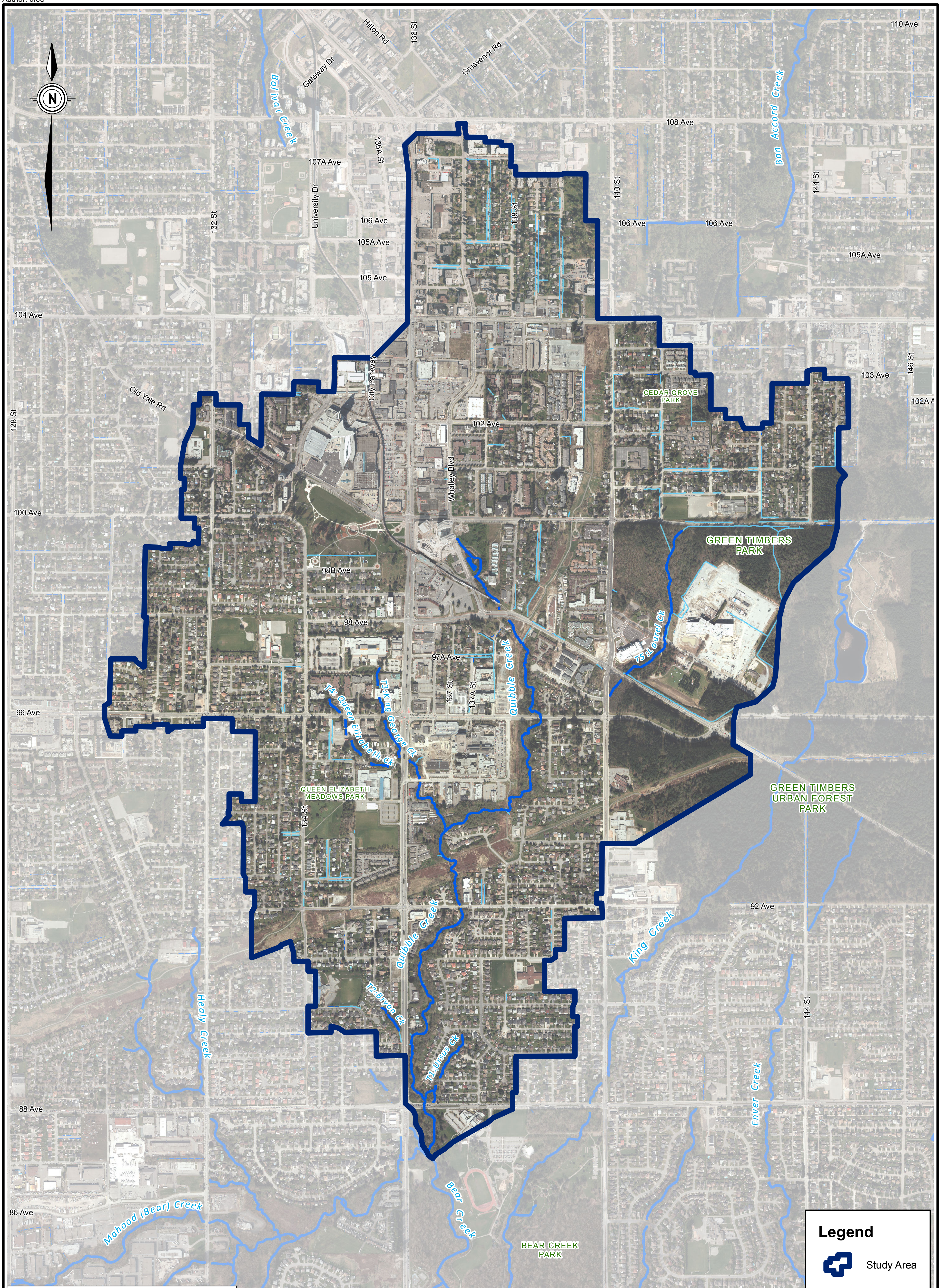

Reference: Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.

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2011 Air Photo of Watershed

Figure 1-1

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Section 2

Overview of Quibble Creek Study Area

2. Overview of Quibble Creek Study Area

2.1 Quibble Creek Watershed

Location and Description

Quibble Creek watershed is located in the north-west quadrant of the City of Surrey and is bounded by 108 Avenue to the north, 144 Street to the east, 88 Avenue to the south and 130 Street to the west. The creek's mainstem and three tributaries drain south to Bear Creek. Bear Creek is a major tributary of the Serpentine River which discharges to the Pacific Ocean at the Mud Bay Estuary.

The Quibble Creek watershed is approximately 656 ha, of which 335 ha is the Surrey City Centre core. The remaining 213 ha of the City Centre core is outside the Quibble Creek watershed and drains to Bolivar Creek. Quibble Creek is a highly developed watershed with total impervious area coverage of approximately 65%. The current land use within the City Centre core is mostly commercial, industrial, multi-family residential and single family residential. Single family residential development and the Green Timbers Park take up the majority of the land outside the City Centre core within the Quibble Creek watershed. Despite the high level of urbanization of the watershed, previous reports indicate a high level of roof leader disconnection in the residential areas (approximately 80%). Disconnected roof leaders along with approximately 8 km of existing open channel ditches in residential areas contribute to decreased connectivity of the developed impervious area to the creek in this watershed.

Watershed and Creek Characteristics

A number of background reports and GIS layers were available for the study. This data was supplemented by engineering and environmental field inventories. Background information reviewed for the project is listed and described in Appendix A. Appendix B provides detailed findings of the engineering inventory while Appendix C provides detailed findings of the environmental inventory. The following table and Figures 2-1 to 2-4 summarize the key study area characteristics.

Table 2-1: Drainage Overview

Description	Quibble Creek Study Area
Drainage Area	• 656 ha total, including: • 335 ha in the City Centre core (51% of the watershed).
Stream Structure	• 3.2 km Quibble Creek; • 0.9 km King George Creek; • 0.5 km Laurel Creek; • 0.3 km Ursus Creek; • 0.1 km Bryan Creek ; • 0.3 km Queen Elizabeth Creek. Figure 1-1 shows the Quibble Creek and its three main tributaries.
Topography	• Topography ranges from El. 112 m (on 144a St., just south of 102b Ave.) to El. 32 m (on 88 Ave. and King George Blvd.). Figure 2-1 shows the topography.
Land Use	Existing: • 36% single family residential, 8% multi-family residential, 26% commercial, 1% institutional, 8% parks and 21% right-of-way. • TIA is 67%. Future – based on current OCP and the Surrey City Centre NCP: • 31% single family residential, 19% multi-family residential, 18% commercial, 1% institutional, 6% parks, 25% right-of-way. • TIA is 74%. Figure 2-2 shows existing zoning and Figure 2-3 shows the Future Land Use.
Drainage	• Quibble Creek drains south to Bear Creek, which then discharges into the Serpentine River which outfalls into the Strait of Georgia at the Mud Bay Estuary. • Existing storm sewers range in size from 75 mm to 2965 mm (the largest pipes are structures for stream conveyance or culverts).
Hydraulic Structures	• System includes 66 km of conduits. • 1424 conduits and 1541 manholes were modelled in the drainage system for Quibble Creek watershed. • Stream crossings include culverts and bridges. Figure 2-1 shows an overview of the drainage system.
Erosion	• 41 erosion sites were identified and ranked (30 low risk sites, 9 medium risk sites, and 2 high risk sites) during the engineering field inventory as shown on Figure 3-1.
Obstructions	• 14 obstruction sites were identified during the engineering field inventory as shown on Figure 3-2.
Soils	• 4% Till; • 36% Sand; • 60% Silt and Clay. Figure 2-4 shows the soil distribution in the watershed based on available mapping.

2.2 Land Use

Existing Land Use

Existing land use in the study area is shown in Table 2-2 below and on Figure 2-2.

Table 2-2: Existing Land Use

Study Area	Area (hectares)	Percentage of Total Area	Average Impervious Percentage (TIA)
Single Family Residential	234	36%	55%
Multi-Family Residential	54	8%	66%
Industrial/Commercial	171	26%	85%
Institutional	9	1%	82%
Parks	49	8%	10%
Right-of-way	139	21%	88%
TOTAL	**656**	**100%**	**67%**
Note: Values based on City of Surrey GIS Zoning layer, 2011			

Future Land Use

Future projected land use was developed for this project based on the City's OCP and the Surrey City Centre NCP. Impervious areas are expected to increase throughout the watershed on average based on development of rezoned and currently vacant land (industrial and institutional zoning) and re-development of existing single and multi-family residential to higher density (and higher impervious land-cover) usage.

Table 2-3: Future Land Use

Study Area	Area (hectares)	Percentage of Total Area	Average Impervious Percentage (TIA)
Single Family Residential	203	31%	67%
Multi-Family Residential	125	19%	84%
Industrial/Commercial	116	18%	90%
Institutional	10	1%	80%
Parks	39	6%	10%
Right-of-way	163	25%	80%
TOTAL	**656**	**100%**	**74%**
Note: Values based on City of Surrey GIS OCP Zoning layer			

The projected increase in impervious area (Total Impervious Area, or TIA) from existing to future land use is:

67% (Existing) ⇒ 74% (Future)

These impervious area values are based on an amalgamation of the City's Design Criteria values and GIS analysis of aerial photos to assess typical impervious coverage for older existing vs. new and changing land use in this area of the City.

Future OCP land use in the study area is shown on Figure 2-3.

2.3 Surficial Geology

To determine the characteristic of the surficial geology, information from Natural Resources Canada and the Geological Survey of Canada was reviewed. These sources suggest that the Quibble Creek floodplain within the study area is underlain principally by sand. The remaining portion of the study area appears to be underlain by glacial till and silt/clay.

Refer to Figure 2-4 for soils mapping, which shows the approximate boundaries of the different soil types.

While the soils information available must be considered approximate only, it indicates that a significant portion of the watershed is underlain by sand or sandy soils, which are beneficial for infiltration of rainwater. As discussed further in Section 5, the presence of well-draining (high infiltration rate) soils in the watershed provides Quibble Creek some amount of protection from the impacts of development and are a valuable asset to the watershed health for stormwater management.

The well-draining soils in the watershed are the "sand" areas on Figure 2-4 with a typical published infiltration rate of approximately 210 mm/hr. The poorly-draining soils in the watershed are the "silt & clay" and "till" areas with a typical published infiltration rates of approximately 1 mm/hr. Site specific infiltration tests are needed to confirm the infiltration rate as there can be high variability in soils encountered relative to the soils mapping.

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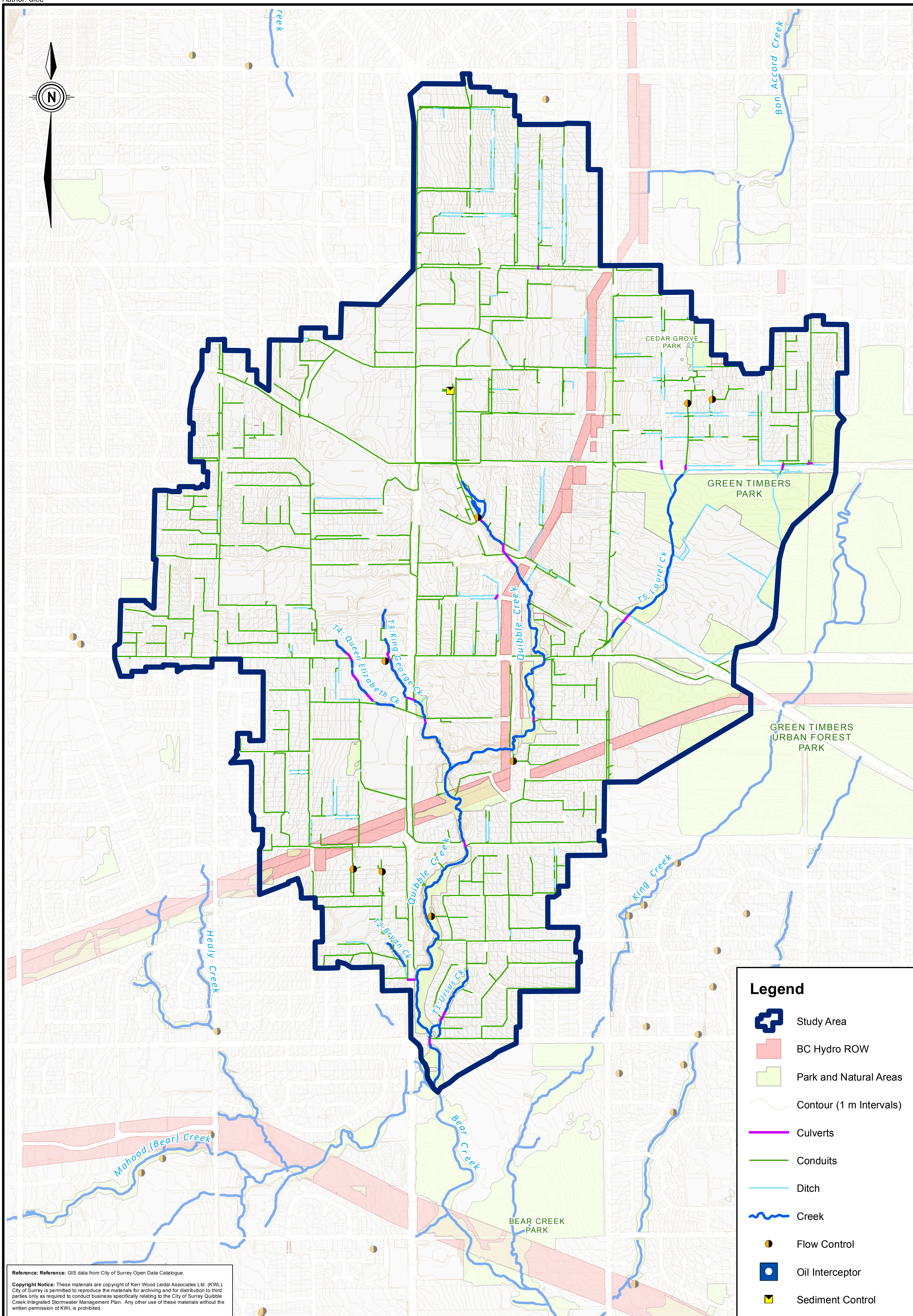

Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

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Topography and Storm Sewers

Figure 2-1

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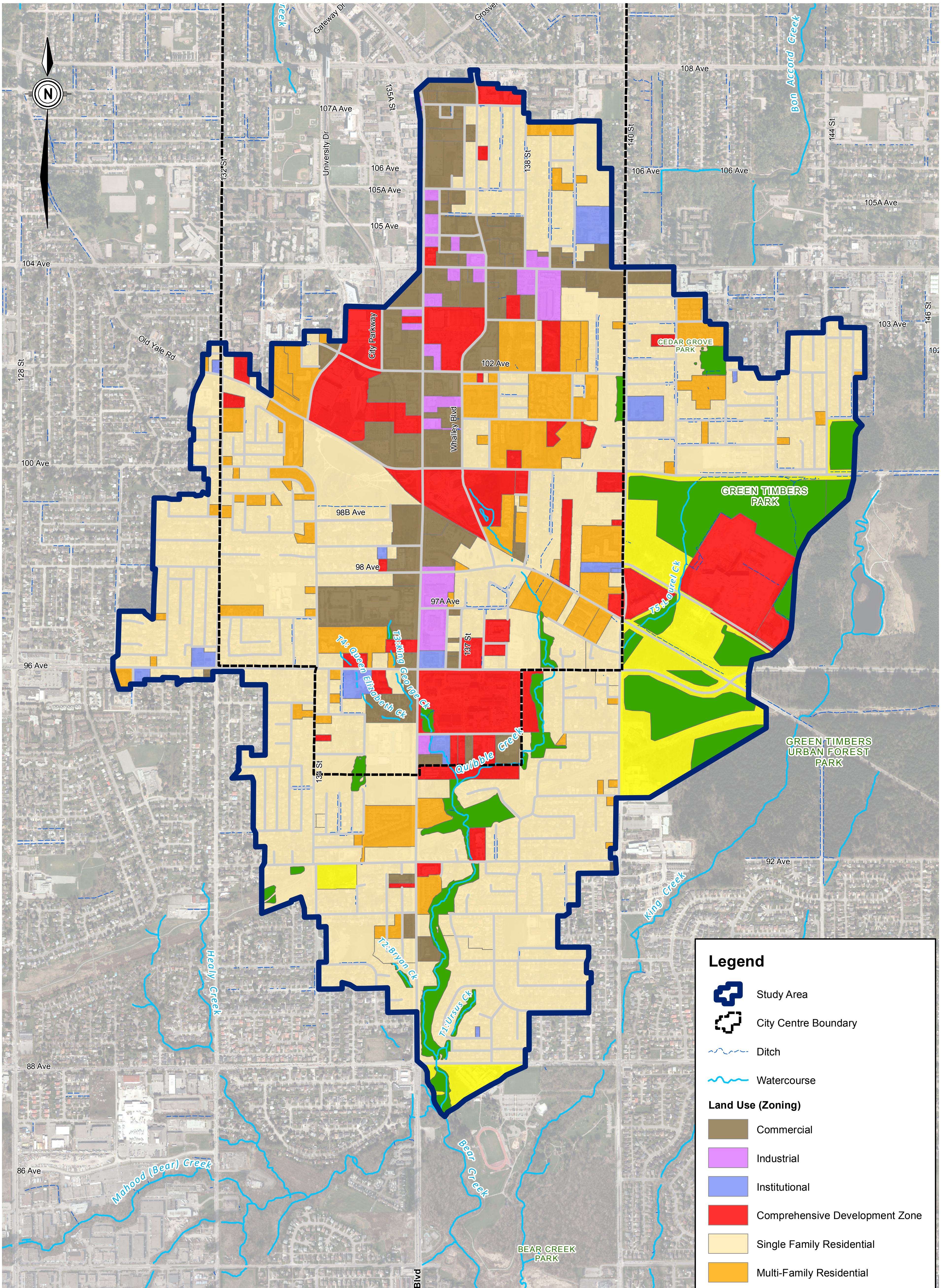

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Existing Zoning

Figure 2-2

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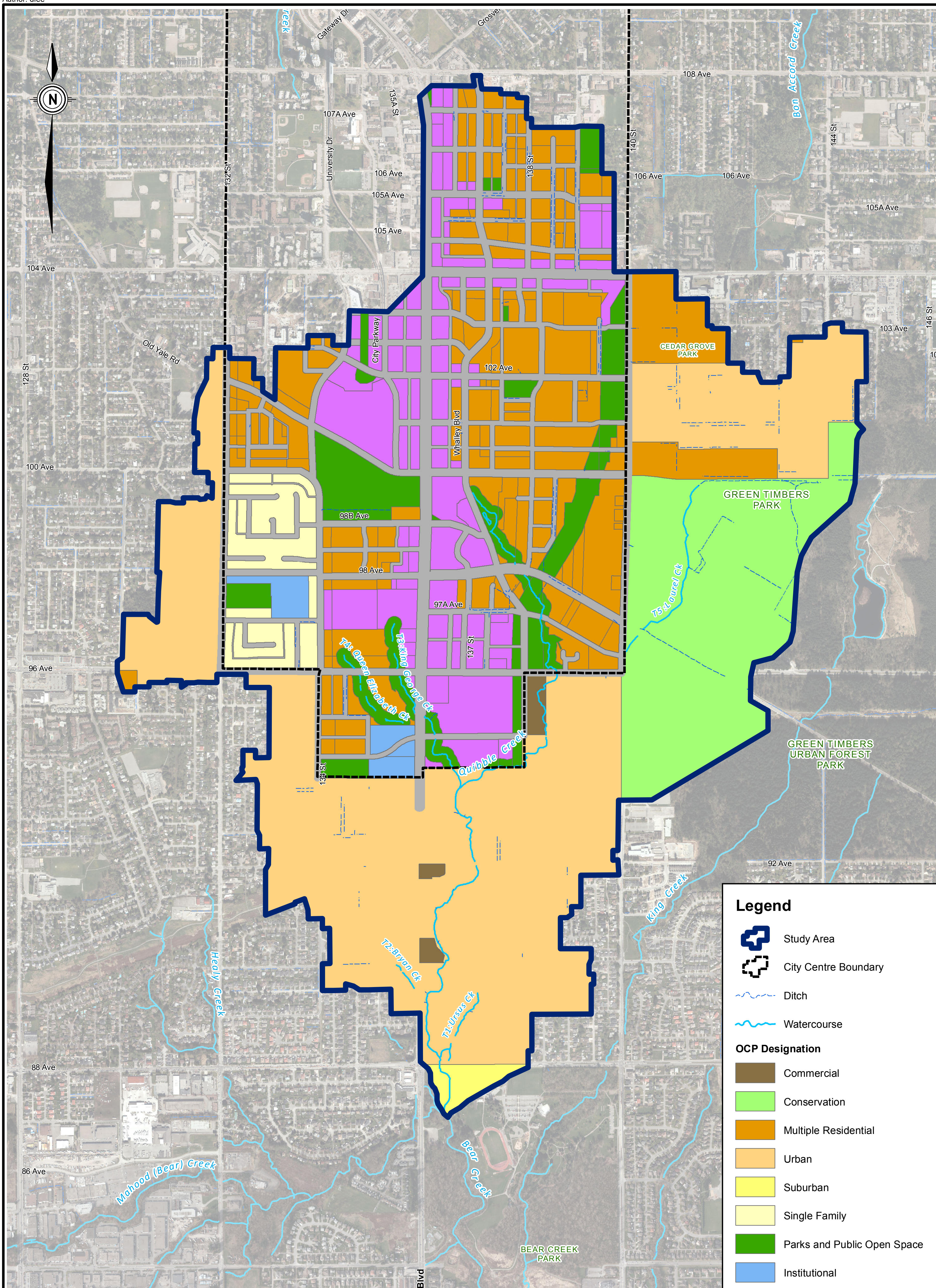

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OCP and City Centre NCP Land Use

Figure 2-3

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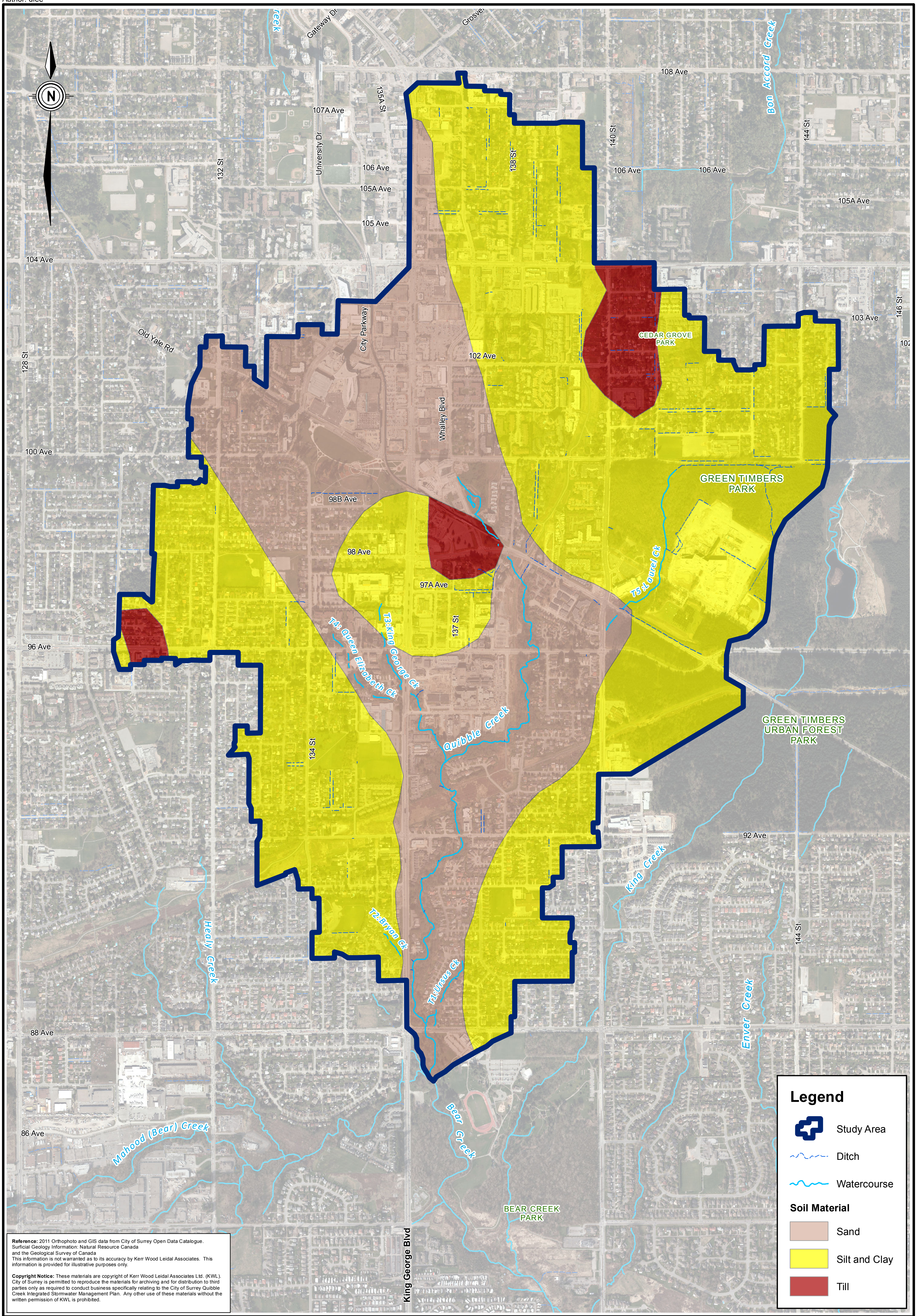

Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.
Surficial Geology Information: Natural Resource Canada
and the Geological Survey of Canada
This information is not warranted as to its accuracy by Kerr Wood Leidal Associates. This information is provided for illustrative purposes only.

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Soils Map

Figure 2-4

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Section 3

Engineering Field Inventory

3. Engineering Field Inventory

KWL undertook an engineering field inventory in May 2012. The scope of work included the main stem of Quibble Creek and the 3 tributaries (142 Street, 135 Street, and King George Highway). The purpose of the inventory was to supplement the City of Surrey's existing geographic information system (GIS) database by locating, photographing and assessing the following features along the creek main stem and each major tributary:

- Significant bank or channel erosion sites;
- Channel obstructions; and
- Hydraulic structures and stormwater outfalls.

The City provided Orthophotos and GIS data showing the storm sewer collection system, the stream and its tributaries, outfalls, and road crossings. This data served as background information and was used to plan the field inventory. The findings of the field inventory are summarized in GIS layers (shown on Figures 3-1 to 3-4) and summary tables (included in Appendix B) for each of the following categories: erosion sites, obstructions, culverts and outlets.

The terms left and right in this report refer to the left and right side of the creek channel when looking downstream. The detailed observations and findings are described in Appendix B.

3.1 Erosion

As part of the engineering field inventory, KWL carried out an assessment of bank instability sites in Quibble Creek. The bank instability assessment consisted of the following components:

- Review of previous ravine stability assessment studies (completed by other consultants in 2002, 2005, 2007, and 2009) to identify sites of active erosion and instability along Quibble Creek.
- A field survey to assess the condition of previously identified erosion sites and to identify new incidents of erosion, bank instability and debris accumulations in stream channels.
- Comparison of photos and data assessment sheets from the 2012 field inventory to those included in the 2009 ravine stability assessment prepared by Web engineering.
- Evaluation of the progression of ongoing erosion or bank instabilities and of the effectiveness of remediation works conducted as a result of the previous studies.

Tables 3-1 to 3-4 summarize major erosion and obstruction issues in the watershed. The erosion GIS layer contains the locations of observed erosion sites, the severity of the erosion, the length, width, and height of the erosion, and comments or observations of the erosion and causes. See Figure 3-1 and Table B-1 in Appendix B for the erosion observations.

Erosion Risk Criteria

The relative risk assessment completed as part of this field inventory was based on the observations of the site made during fieldwork. A relative risk designation was assigned to each site as defined as follows:

- High Risk: likely or immediate risk to public safety, or damage to structures or infrastructure.
- Medium Risk: no anticipated risk to structures and no significant risk to public safety, but increasing risk may develop over time. May involve some impact to yard areas, but no immediate risk to structures.
- Low Risk: minimal risk of impact to private property or public safety in the near or foreseeable future.

The 2012 KWL field inventory identified at total of 41 erosion sites in Quibble Creek main stem and tributaries. Based on the information collected during the fieldwork, 2 of the sites are designated as high risk, 9 as medium risk, and 30 as low risk sites.

3.2 Channel Obstructions

Tables 3-1 to 3-4 summarize major erosion and obstruction issues in the watershed. The obstructions GIS layer contains the type of obstruction, the location of the obstruction, whether the obstruction is a barrier in the stream and comments or observations for each obstruction. See Figure 3-2 and Table B-2 in Appendix B for more details.

The 2012 field inventory identified a total of 14 obstructions within the creek and tributary channels. The obstructions mostly consisted of fallen logs and wooden debris. On a few occasions, build-up of debris was restricting flow to culverts, but posed no apparent major risk.

The culverts and bridges GIS layer contains the location, material, condition and comments on the condition of the structures. See Figure 3-3 and Tables B-3 to B-5 in Appendix B.

The outfalls GIS layer contains the location, material, condition and comments on the condition of the structures. See Figure 3-4 and Table B-6 in Appendix B.

A relative condition designation was assigned to each outfall as defined as follows:

- Good: Structure is stable; minor defects acceptable.
- Fair: Some structural defects, but not likely to increase in severity in the future.
- Poor: Structural defects likely to increase in magnitude over time.

Key observations from the drainage inventory include:

Table 3-1: Key Erosion and Obstruction Observations - Quibble Creek Main Stem

Observation	Site ID	Location	Photo No.	2012 Risk Rating	Description
Obstruction	147.64	Upstream of Detention Pond at Whalley Blvd	595	Low	Sealed culvert preventing flow to quality control pond.
Obstruction	147.59	Quibble Creek at 136a Street	524	Low	Fallen log restricting high flows.
Erosion	147.17	70m Upstream of the Quibble Creek and 92nd Street crossing	536	Medium	Erosion of bank continuing since 2011 assessment.
Erosion	147.19	200m Downstream of 94a Avenue and 138 Street	543	Medium	Recent erosion at base of the bank.
Erosion	147.24	50m Upstream of 94a Avenue and 138 Street	556	Medium	Private shed and fence are at risk of damage from undercutting of bank. No sign of further erosion since 2011 assessment.

Table 3-2: Key Erosion and Obstruction Observations – T3 King George Creek

Observation	Site ID	Location	Photo No.	2012 Risk Rating	Description
Erosion	147.55	120m Downstream of the Quibble Creek and 94A Ave. crossing	669	High	Undercutting of a tree and the surrounding bank. Should investigate further.

Table 3-3: Key Erosion and Obstruction Observations – T4 Queen Elizabeth Creek

Observation	Site ID	Location	Photo No.	2012 Risk Rating	Description
Obstruction	147.81	5m Upstream of T4:Queen Elizabeth Creekand 96 Avenue	641	Low	Debris build up on culvert grate is restricting flow. Should investigate further.
Obstruction	147.83	160m Downstream of T4:Queen Elizabeth Creekand 96 Avenue	650	Medium	Culvert inlet blocked with debris.

Table 3-4: Key Erosion and Obstruction Observations – T5 Laurel Creek

Observation	Site ID	Location	Photo No.	2012 Risk Rating	Description
Erosion	147.48	10m Upstream of the T5:Laurel Creek and 140 Street crossing	606	Medium	Undercutting of a tree and the surrounding bank. Tree is at risk of falling on the roadway. Should investigate further.
Erosion	147.49	5m Upstream of T5:Laurel Creek and Fraser Hwy crossing	613	High	Erosion of creek bank on both sides of a concrete culvert. Hydro pole is being uncut and at risk of falling on the roadway.
Obstruction	147.66	250m Upstream of T5:Laurel Creek and Fraser Hwy crossing	632	Low	Debris buildup on culvert grate and restricting flow.

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Field Inventory - Observed Erosion Sites and Ratings

Figure 3-1

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Field Inventory - Observed Obstruction Sites

Figure 3-2

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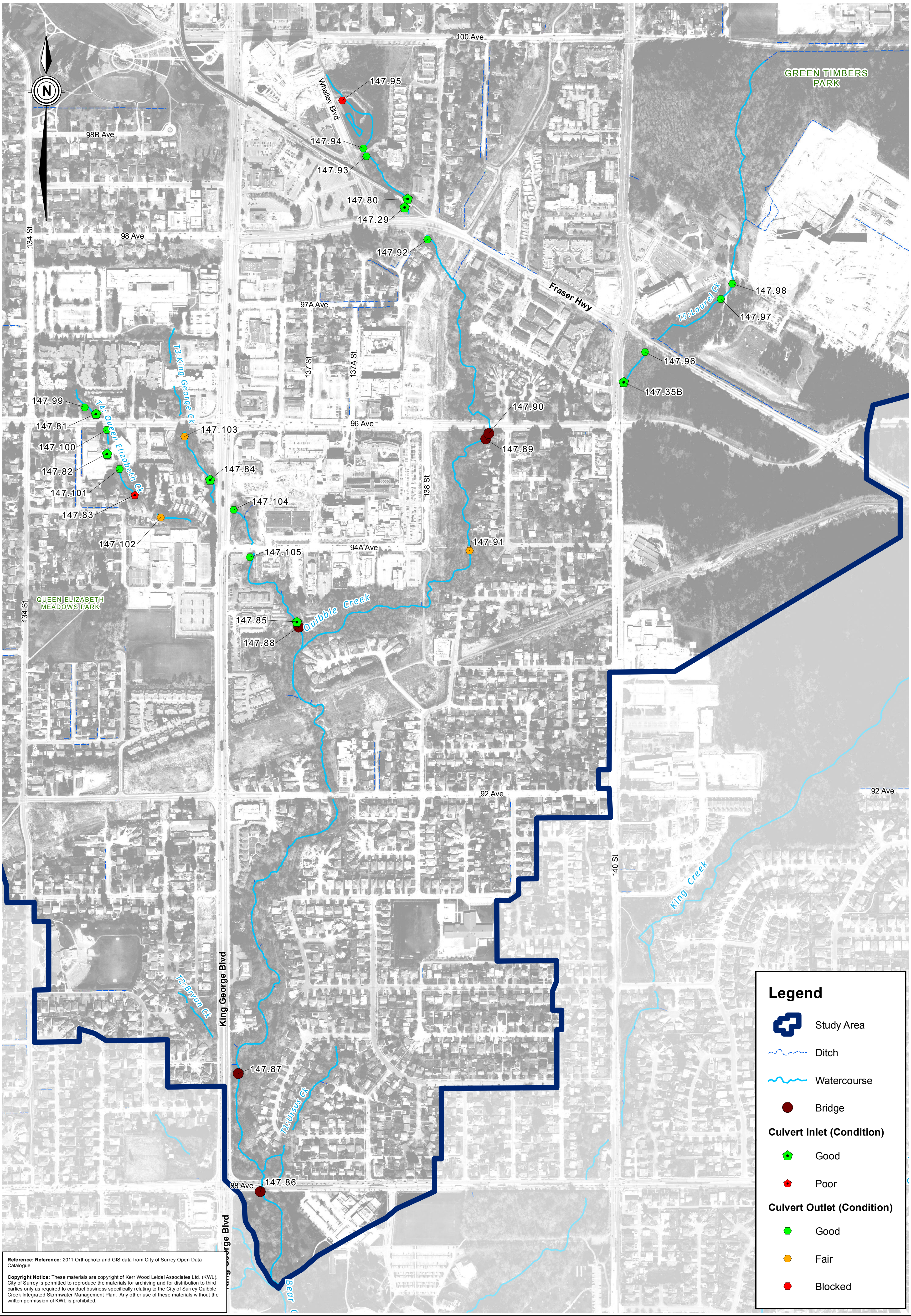

Reference: Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.

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Field Inventory - Inspected Culverts and Bridges

Figure 3-3

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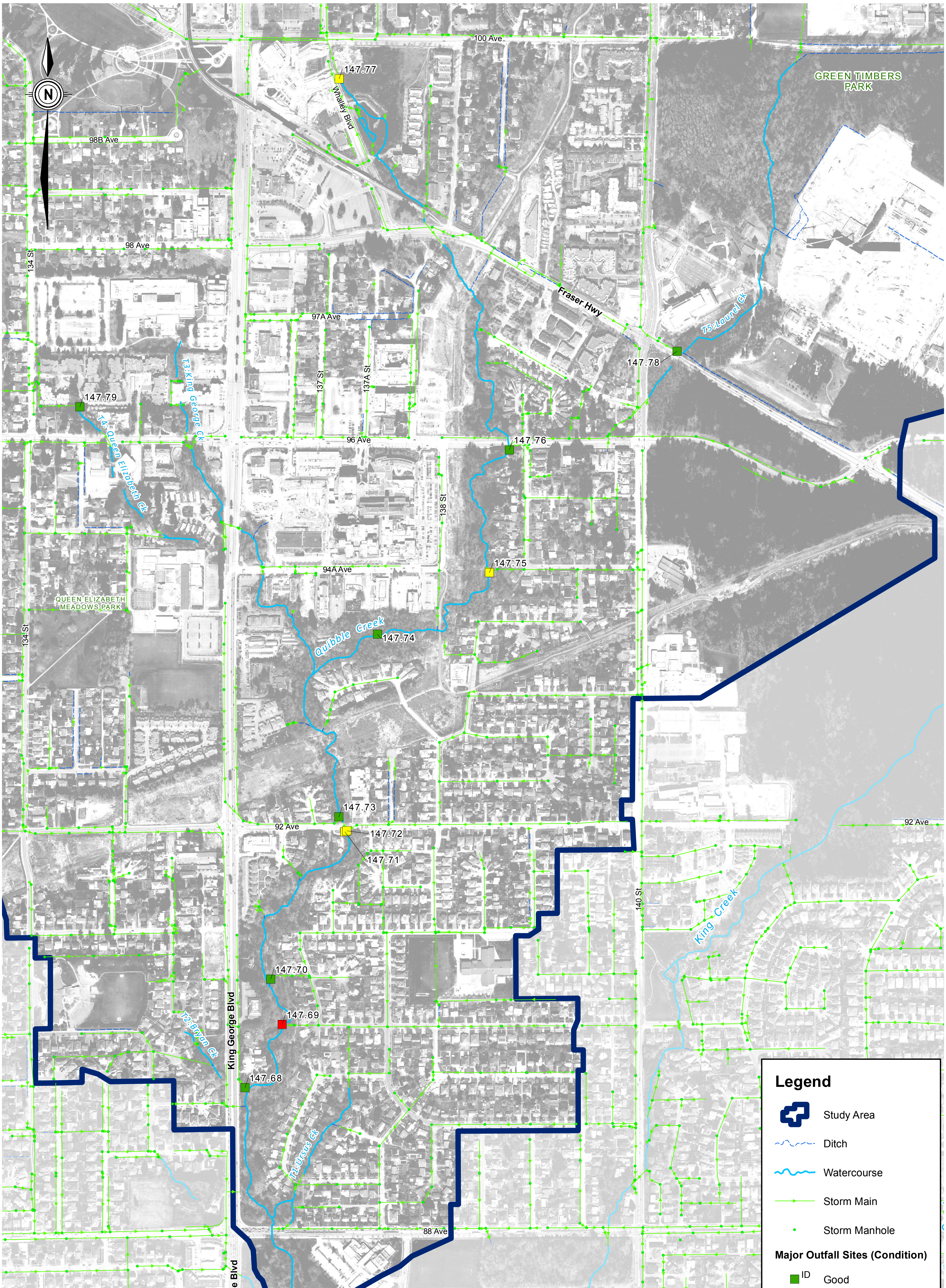

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Field Inventory - Inspected Storm Outfalls

Figure 3-4

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Section 4

Environmental Inventory and Assessment

4. Environmental Inventory and Assessment

4.1 Key Findings

- Quibble Creek is remarkable because of good quality instream and riparian habitat despite the high level of watershed urbanization. It is also important as an accessible fish-bearing stream in proximity to Surrey's developing City Centre.
- Good quality instream habitat supports spawning and rearing habitat for wild coho salmon, chum salmon, and cutthroat trout. One hundred and twenty-two adult coho and 537 adult chum were observed spawning in Quibble Creek during a 2-day survey in November 2012, mainly in the main stem.
- The water quality survey found conditions typical of urbanized streams in Metro Vancouver. The survey did not find any specific sites or stream sections with elevated or unusual water quality characteristics which would indicate specific sources of contamination (e.g., "hot spots").
- Metals in sediment (an indicator of urbanization) were generally lower than other urban streams in Metro Vancouver. This result was unexpected given the level of urbanization in the Quibble Creek watershed.
- B-IBI (Benthic Index of Biotic Integrity) was used to summarize benthic invertebrate (streambed insect) data. Mean B-IBI was 14.1 which is consistent with the high level of urbanization in the Quibble Creek watershed. The benthic invertebrate community in Quibble Creek has been stable between 2009 and 2012 with no clear trends in changing taxa presence or absence.
- A total of 87 ha (13%) of the Quibble Creek watershed was forested in 2011. Approximately 20 ha (3%) of watershed forest cover has been lost since 1995. Approximately 22 ha (60%) of the Quibble Creek riparian zone is currently forested, mainly with deciduous forest. Riparian forest cover has remained stable over the past 16 years largely because of regulation of development in riparian areas.
- The density of large instream wood and deep pools (indicators of fish habitat quality) was lower in Quibble Creek than less urbanized streams. This suggests that instream habitat restoration focusing on increasing structural complexity could increase fish habitat value.
- Fish passage improvements could improve fish access to tributary streams (Ursus Creek, Laurel Creek) for coho salmon and cutthroat trout.

4.2 Watershed Health

Quibble Creek is remarkable because of good quality instream and riparian habitat despite the high level of urbanization. Kistritz (1998) stated that "Quibble Creek is a contradiction" where ecological conditions were not consistent with the high level of watershed urbanization. The forested riparian corridor is an important factor sustaining ecological health. Hydrologic resilience related to groundwater infiltration and sustained summer base flows is also important.

Water and Sediment Quality

The term water quality refers to the chemical, physical and biological conditions of water and the degree to which it is impaired or degraded by natural or anthropogenic factors. Good water quality in streams is vital to ecosystem functioning and aquatic life, such as fish, as well as human uses for drinking water recreation, and aesthetics. A summary of water quality work and parameter values completed to date is provided below in Table 4-1 and on Figure 4-1.

- Initial survey of general water quality parameters completed in late June 2012;
- Analysis of lab-based parameters (e.g., fecal coliforms, total metals) completed in late summer 2012;
- Two instream probes were used to monitor temperature between March and September 2012; and

The water quality survey found conditions typical of urbanized streams in Metro Vancouver. The survey did not find any specific sites or stream sections with elevated or unusual water quality characteristics which would indicate specific sources of contaminations (e.g., "hot spots").

Table 4-1: General Water Quality Parameters Measured (June 21, 2012)

Parameter	Units	Parameter Values		
		Minimum	Maximum	Mean
Water Temperature	°C	13.0	17.7	14.5
Dissolved Oxygen	mg/L	8.9	22.0	12.1
Specific Conductivity	μS/cm	187	746	327
pH	pH units	5.46	8.29	7.67
Turbidity	NTU	0.6	67.5	3.7
Oxygen Reduction Potential (ORP)	-	-5.46	8.29	7.67

Key results of the water quality survey were:

- Specific conductivity was elevated (mean of 327 uS/cm) relative to undisturbed streams (typically <20 uS/cm), however, it was consistent with other heavily urbanized streams in Metro Vancouver such as Still Creek in Vancouver and Wagg Creek in North Vancouver.
- Dissolved oxygen levels were generally above 10 mg/L which is suitable for salmonid spawning and rearing.
- pH ranged from 5.47 to 8.29 (mean of 7.67) which is more variable than some watersheds but still within expected ranges.
- Turbidity was low (mean of 3.7 NTU) but elevated at one storm outfall (67.5 NTU at 91st Ave). If this measurement was removed, the mean turbidity was 2.1 NTU.

Water temperature monitoring showed two noteworthy results:

- During the period where both probes were operational, water temperature was often 0.8 to 1.7 degree higher at the upstream monitoring site. This was expected based on the lack of shading provided by the regenerating riparian forest.
- The maximum temperature in the summer of 2012 was around 20^{o}C at the downstream monitoring site and by extrapolation was likely close to 22^{o}C at the upstream site. This is higher than the recommended range for salmonid habitat but below levels which cause fish mortality. However, these values are not considered unusual for urban streams in Metro Vancouver. Winter temperature was not measured.

Stream sediments accumulate metals and other contaminants from a variety of sources in developed watersheds, and analysis of sediments provides a complimentary assessment of environmental chemistry when combined with water quality tests. They are also useful for long-term monitoring of stream conditions because they are much less variable than water quality measurements.

Key results were:

- No samples were above BC Working Sediment Quality Guidelines (BCSQGs) for metals.
- Total metals in Quibble Creek sediment were generally lower than other urban watersheds in Metro Vancouver. This result was unexpected given the level of urbanization in the Quibble Creek Watershed. It may indicate that sediment-bound contaminants are trapped in the on-line sediment pond south of 100th Avenue.
- Total metals in sediment collected from one site in lower Quibble Creek were lower than BC Sediment Quality Guidelines, and lower than other urban streams in Metro Vancouver.

Benthic Invertebrates

Benthic invertebrates (streambed insects) are indicators of stream condition and can be monitored over time to track changes in stream or watershed health. B-IBI (Benthic Index of Biotic Integrity) is a common multi-metric method for summarizing benthic invertebrate data and has been used extensively to measure the condition of small streams in Metro Vancouver. Figure 4-1 shows the location of benthic sampling. Refer to the data tables (C-1 and C-2) at the end of Appendix C for B-IBI values and benthic taxa by year.

The B-IBI Index operates on a scale of 10 to 50, with 10 representing a degraded watershed and 50 representing a pristine, old growth watershed such as the Olympic Mountains. However, the maximum value observed in lowland streams in the Metro Vancouver is around 35.

Mean B- IBI for all samples was 14.1 which is consistent with the high level of urbanization in the Quibble Creek watershed. Mean taxa (all invertebrates sampled) richness for all samples was 6.7 and mean EPT taxa richness (stoneflies, mayflies, caddisflies) was 1.1 (range of 1 to 2).

The benthic invertebrate community in Quibble Creek has been stable between 2009 and 2012 with no clear trends in changing taxa presence or absence. The community is dominated by three taxa: the pollution-tolerant stonefly *Baetis tricaudatus*, a midge (*Ceratopogoninae*) closely related to blackflies, and Oligochaete worms. Together they accounted for over 95% of the individuals sampled, with *Baetis tricaudatus* being the most abundant (40% of all individuals sampled). All three are characteristic taxa in urban streams in Metro Vancouver.

4.3 Watershed and Riparian Forest Cover

Watershed and riparian forest cover are indicators of stream and watershed health and measure the effect of changing land use on hydrology, water quality, and other components of stream ecosystems. Riparian forest cover or integrity (RFI), in combination with watershed impervious area and benthic invertebrate sampling, provide data for the Watershed Health Tracking System (WHTS), and will also help to assess the impacts of future land use scenarios. See Figure 4-2 for the watershed and riparian forest cover in the catchments. See Table C-4 in Appendix C for watershed health indicator values.

Table 4-2: Watershed Health Indicators – Watershed and Riparian Forest Cover

Watershed	Total area (ha)	Watershed forest cover (ha)	Watershed forest cover (%)	Riparian forest cover (ha)	Riparian forest integrity (RFI) (%)
Quibble Creek	37.4	86.6	13.2	22.4	59.9

Watershed Forest Cover Conditions

A total of 86.6 ha (13%) of the Quibble Creek watershed was forested (2011). Concentrations of forest are found in the Green Timbers Urban Forest Park area and the Quibble Creek riparian corridor. Approximately 20.1 ha (3%) of watershed forest cover has been lost since 1995.

Riparian Forest Cover Conditions

The riparian area is relatively intact and forms a continuous band except for major road crossings. Approximately 22.4 ha (60%) of the Quibble Creek riparian zone is currently forested, mainly with deciduous forest. Riparian forest cover has remained stable over the past 16 years (22.5 ha in 2011 and 22.4 ha in 1995) largely because of regulation of development in riparian areas. Invasive plants are common in these areas.

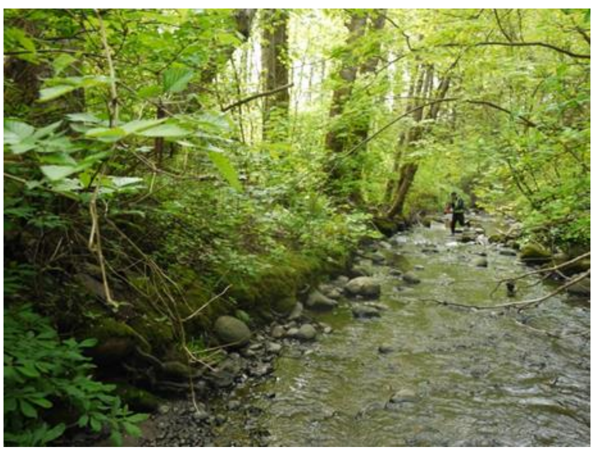


Photo 4-1: Healthy and diverse riparian forests

Photo 4-2: Some encroachment from residential development and invasive species issues

Green Infrastructure Network Analysis

The City's analysis of landscape scale patterns of natural areas and connectivity as part of the Biodiversity Strategy has identified several important parks and riparian areas within and nearby the Quibble Creek watershed. These areas help sustain native fish and wildlife, and also provide ecosystem services such as drainage and water filtration. Initial results of the analysis include:

- Green Infrastructure Network analysis identified Green Timbers Urban Forest and Bear Creek Park as important large natural areas (hubs). The King Creek corridor was identified as a regional corridor (Image 4-1).

- Quibble Creek was considered a local corridor which is longer and more discontinuous than King Creek, and therefore less likely to be used by wildlife. The utility corridor (see local corridor 116 in Image 4-1) is also importance for east-west connectivity to Green Timbers.
- Limited opportunities exist to increase riparian and non-riparian forest cover: the existing stream corridor and watershed are well-developed, limited park space, vegetation management constraints.
- Areas outside of stream or utility corridors are also important for improving landscape-level connectivity. For example remnant tree patches between Green Timbers and the Quibble Creek corridor are important stepping-stone habitats for birds and other mobile wildlife species.
- Tree retention during redevelopment, active tree planting or garden naturalization, street closure or narrowing and park acquisition (as small as single lots) should be emphasized in these areas.

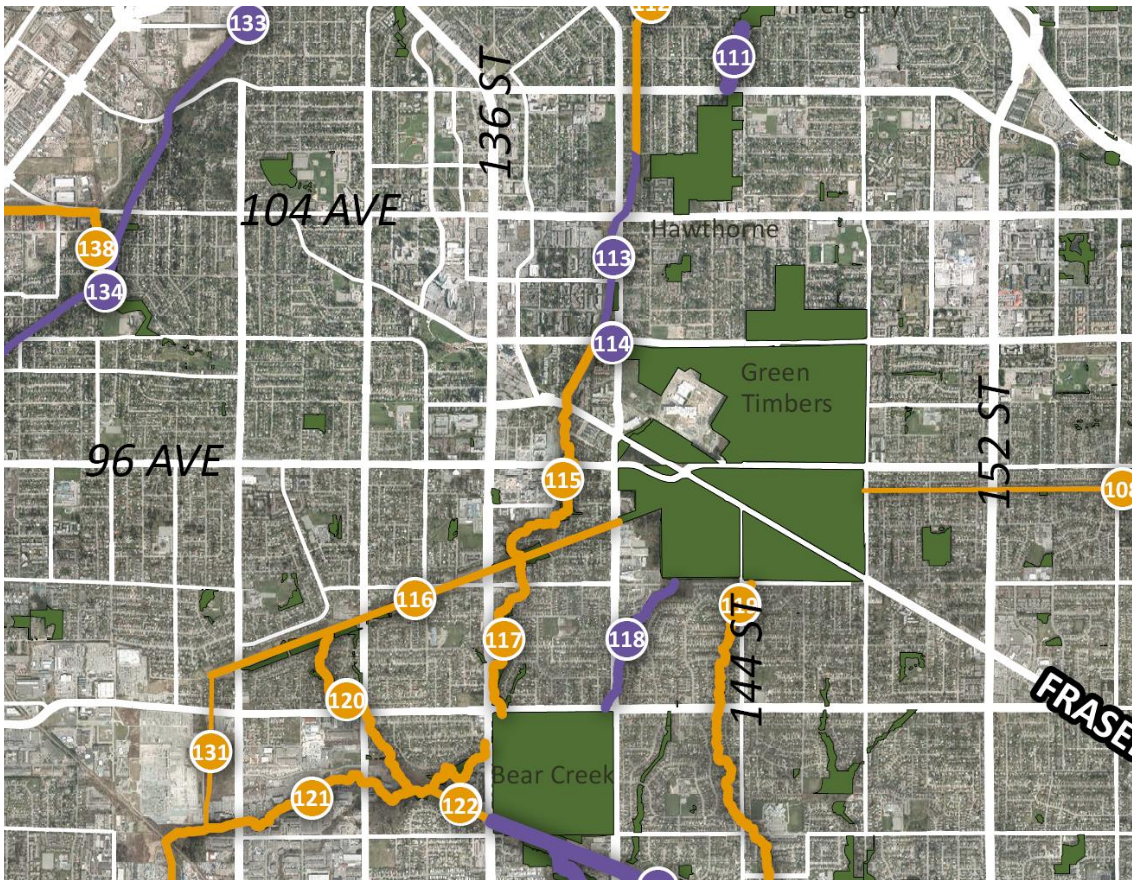


Image 4-1. Landscape scale natural areas and important corridors in or near the Quibble Creek watershed. Purple lines indicate regional corridors and orange lines indicate local corridors (from City of Surrey Biodiversity Strategy, May 2013 draft map).

4.4 Species and Habitat

Fish and Aquatic Habitat

Fish communities, fish passage barriers and fish habitat characteristics were assessed from existing information as well as during field visits in May 2012. The results of the site assessment are summarized on Figure 4-3.

Mean bankfull width in the Quibble Creek main stem in May 2012 was 6.0 m and wetted width was 4.5 m. Instream substrate is predominantly cobble and gravel with lesser amounts of boulder and fine sediment (sand and silt).

A total of 210 pieces of large wood were recorded with an average length of 8.5 m, diameter of 35 cm and volume of 0.91 m^3. The density of large instream wood was 3.2 pieces per 100 m of stream channel which indicates that Quibble Creek is relatively barren of large instream wood compared to natural streams although it is likely similar to most lowland streams in Metro Vancouver. Fifty-two pools deeper than 40 cm were measured in May 2012 and there was no clear pattern or concentration of pool development.

Erosion is not a significant concern in Quibble Creek from the perspective of fish habitat and other environmental values. Low summer flows are not an important limiting factor for fish populations in the mainstem of Quibble Creek at present but do affect smaller tributary streams. However, reduced summer baseflow in the future could negatively impact fish populations.

Fish Community

Information on the fish community in Quibble Creek and its tributaries has not been comprehensively assessed in any one study. The City of Surrey's watercourse classification map summarizes fish presence information based on historical sampling and habitat suitability.

To provide supplemental information, a brief trapping survey using minnow traps was undertaken in early July 2012 in headwater areas to confirm fish presence. Three fish species were captured: juvenile coho salmon, juvenile cutthroat trout, and threespine stickleback. One western brook lamprey was also observed during the survey. Recently emerged juvenile coho fry were also observed throughout the Quibble Creek mainstem in May 2012 but appeared to decline in abundance upstream of 96 Ave.

A survey of adult spawning use was also undertaken on November 15 and 23, 2012 to map the distribution of spawning chum and coho salmon. The mainstem and bottom end of significant tributaries were walked and spawning fish were recorded and mapped using a hand-held GPS. A total of 659 spawning salmon were recorded during the 2-day survey: 122 coho and 537 chum. All spawning was recorded in the Quibble Creek mainstem, except for minor coho (6 fish) and chum (9 fish) use in the lower 320 m of the King George Creek. Other tributary streams were either blocked by impassible culvert barriers or did not have suitable spawning habitats

Error! Reference source not found. summarizes the fish species present in Quibble Creek.

Table 4-3: Fish Species Present or Likely Present in Quibble Creek

Species			Source(s)	Notes
CO	Coho Salmon	*Oncorhynchus kisutch*	Kistritz 1998; 2012 spawner survey; trapping	Native salmonid
CH	Chum salmon	*Oncorhynchus keta*	Kistritz 1998; 2012 spawner survey	Native salmonid
CT	Cutthroat trout	*Oncornhynchus clarki*	Kistritz 1998; 2012 trapping	Native salmonid
CAS	Prickly Sculpin, Western Brook Lamprey,	*Cottus asper*	Kistritz 1998; 2012 trapping survey	Other native fish species
TSB	Threespine Stickleback	*Gasterosteus aculeatus*	2012 observations	Other native fish species
ST	Steelhead Trout may be present	*Oncornhynchus mykiss*	Kistritz 1998	Other native fish species

Riparian Wildlife

Riparian wildlife was not inventoried as part of the ISMP, other than anecdotal observations collected during field surveys. More comprehensive surveys are needed to better understand wild life use in the Quibble Creek watershed and the importance of riparian corridors for wildlife movement from Green Timbers Urban Forest to Bear Creek Park.

Tracks of raccoon and river otter were observed in several locations along the mainstem (particularly in the powerline crossing north of 92 Ave), and red-legged frog (a threatened species) was observed along the mainstem and tributary streams during fish surveys. Coast mole is also abundant in upland riparian areas including Bear Creek Park.

Most of the riparian areas in the watershed are forested with maturing deciduous forest with red alder and black cottonwood. Sitka spruce is the dominant evergreen tree in most areas. Deciduous forests support diverse migratory bird populations but often lack the structural features such as large snags, downed logs, or older conifers to support native squirrels and cavity-nesting species such as woodpeckers. Floodplain wetlands are also rare which limits habitat for pond-breeding amphibians including red-legged frog, Pacific tree frog, roughskin newt, and northwestern salamander.

Species at risk that may occur in riparian areas in the Quibble Creek watershed include Pacific water shrew (Endangered; red-listed), red-legged frog (Special Concern; blue listed), Trowbridge's shrew (blue listed), Oregon forestsnail (Endangered; red-listed), and Pacific sideband (blue-listed). Southern red-backed vole (red-listed) was recorded in Green Timbers Urban Forest. Other than red-legged frog, none have been recorded through recently sampling or observations.

Instream Fish Habitat

The environmental field inventory assessed the condition of instream fish habitat in the mainstem and tributaries of Quibble Creek. The results of the assessment include:

- Fish habitat quality is variable but generally good in Quibble Creek, particularly downstream from 96 Avenue to Bear Creek Park.
- Pieces of large wood (greater than 10 cm in diameter and 2 m long; often called "large woody debris: LWD") and pools >40 cm deep were mapped as indicators of fish habitat value. Large wood and deep pools are important for sustaining salmon and trout populations, particularly juvenile coho

salmon and cutthroat. Large wood is an important structural feature in small coastal streams which is reduced or eliminated by urbanization.

- Instream habitat restoration sites (stream segments) were identified based on existing channel conditions and access to the stream channel. Suitable techniques include large wood or wood clusters where flood risk is minimal and boulder groups where there is a risk to infrastructure if large wood is used.
- There are also limited opportunities for the creation of off-channel (floodplain) habitats such as ponds, channels, and wetlands because of shallow ravine topography (3 potential sites were identified).
- Good quality instream habitat supports spawning and rearing habitat for wild coho salmon, chum salmon, and cutthroat trout. In November 2012, 122 adult coho and 537 adult chum were observed spawning in Quibble Creek, mainly in the mainstem. Fish sampling and observations confirmed the City's watercourse classification for Quibble Creek based on fish distribution.
- Fish passage is not a major concern (predominantly bridges and fish passable culverts) for fish populations but culverts limit fish access from the mainstem to tributary streams.

Photo 4-3: Pool and Riffle Habitat with Stable Substrates

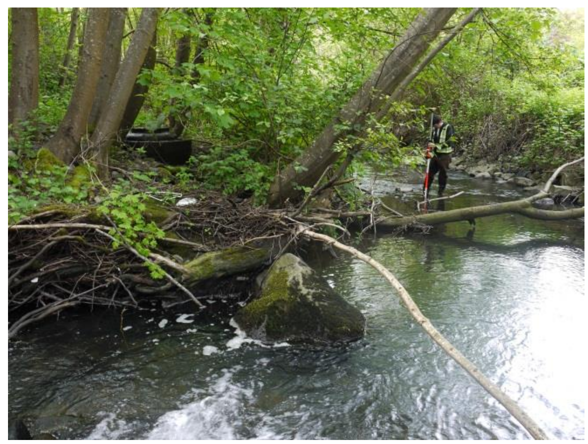
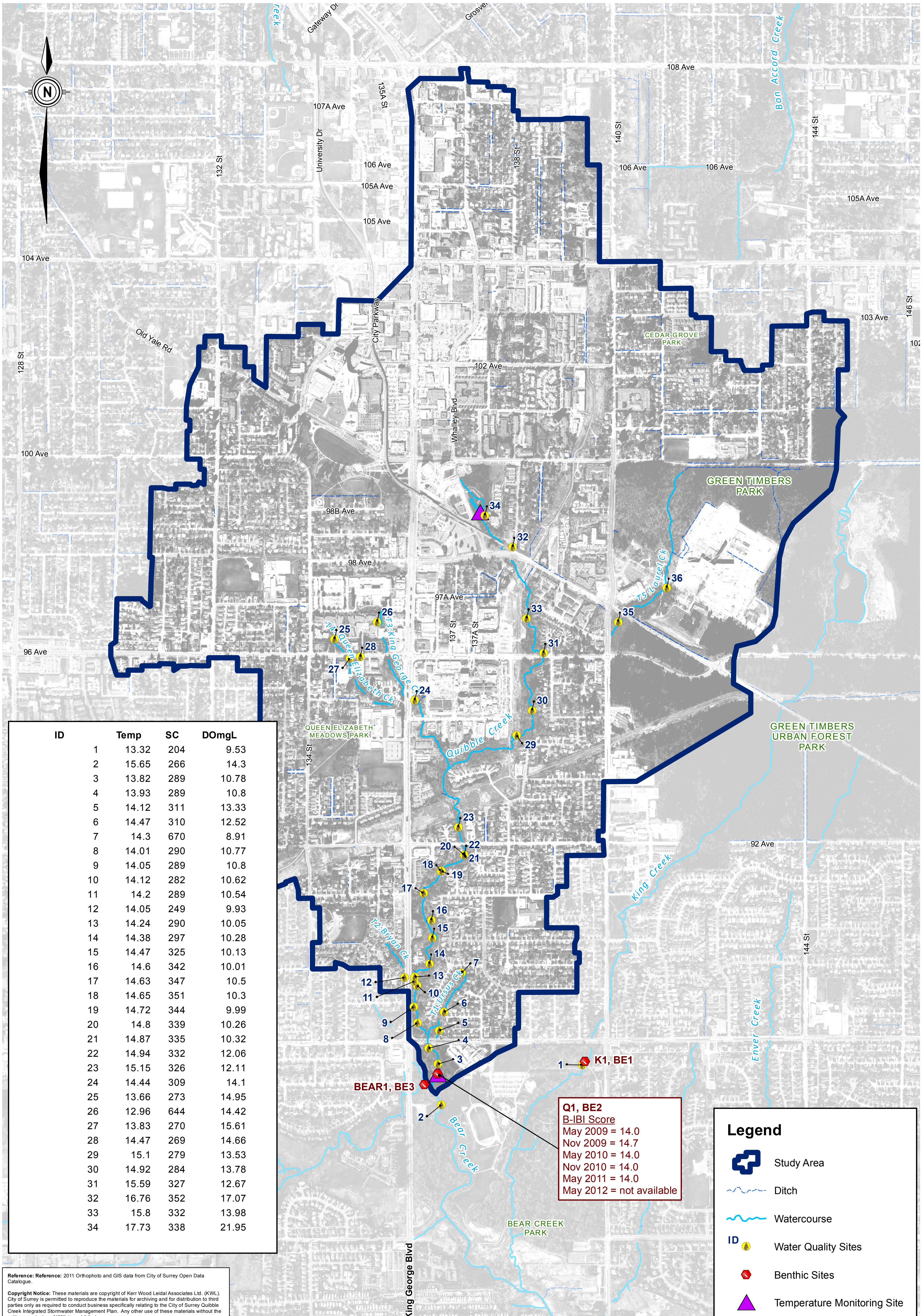


Photo 4-4: Structural Complexity with Large Wood



ID	Temp	SC	DOmgL
1	13.32	204	9.53
2	15.65	266	14.3
3	13.82	289	10.78
4	13.93	289	10.8
5	14.12	311	13.33
6	14.47	310	12.52
7	14.3	670	8.91
8	14.01	290	10.77
9	14.05	289	10.8
10	14.12	282	10.62
11	14.2	289	10.54
12	14.05	249	9.93
13	14.24	290	10.05
14	14.38	297	10.28
15	14.47	325	10.13
16	14.6	342	10.01
17	14.63	347	10.5
18	14.65	351	10.3
19	14.72	344	9.99
20	14.8	339	10.26
21	14.87	335	10.32
22	14.94	332	12.06
23	15.15	326	12.11
24	14.44	309	14.1
25	13.66	273	14.95
26	12.96	644	14.42
27	13.83	270	15.61
28	14.47	269	14.66
29	15.1	279	13.53
30	14.92	284	13.78
31	15.59	327	12.67
32	16.76	352	17.07
33	15.8	332	13.98
34	17.73	338	21.95

Reference: Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.

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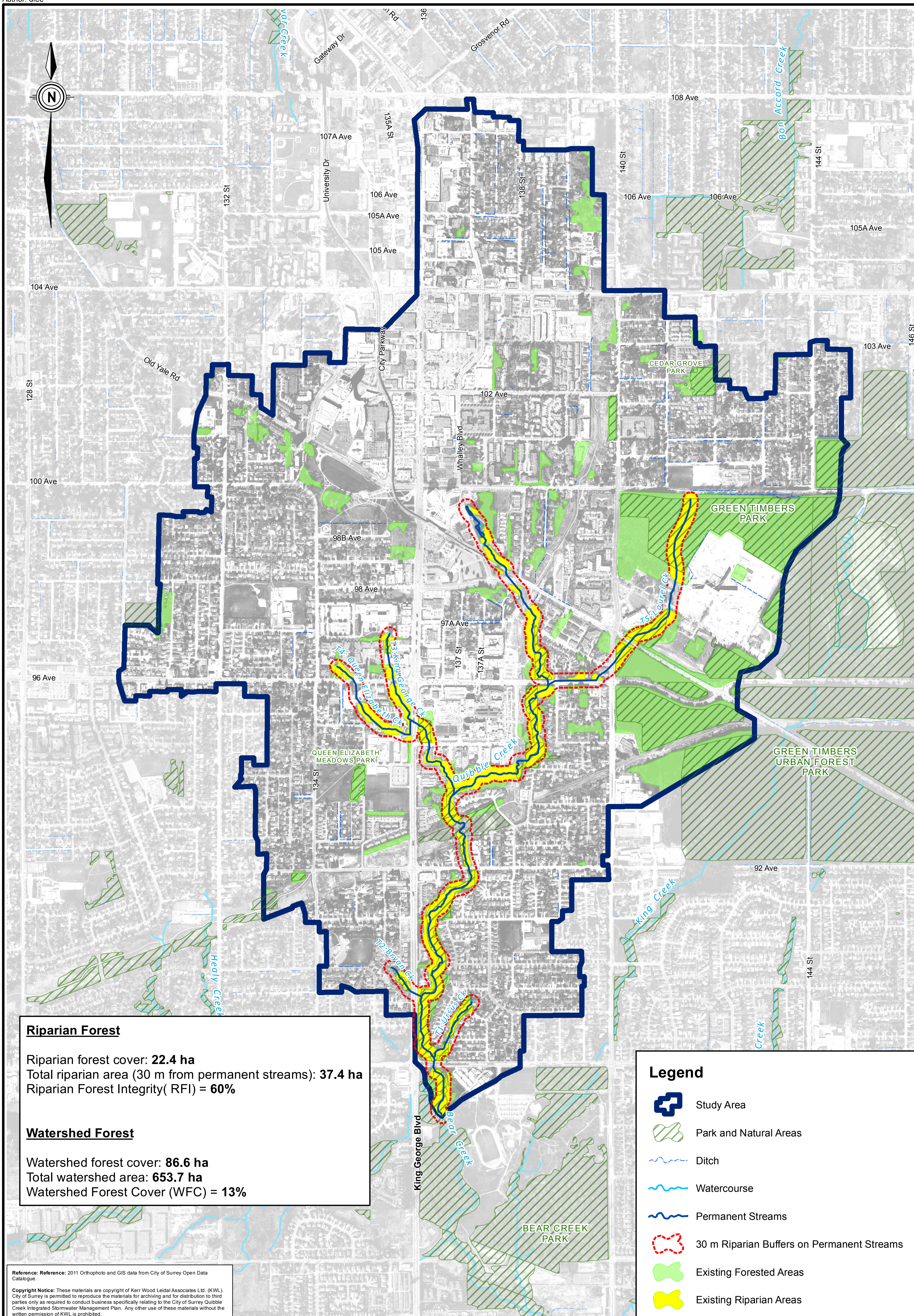
Environmental Sampling Sites

Figure 4-1



Riparian Forest

Riparian forest cover: **22.4 ha**
Total riparian area (30 m from permanent streams): **37.4 ha**
Riparian Forest Integrity(RFI) = **60%**

Watershed Forest

Watershed forest cover: **86.6 ha**
Total watershed area: **653.7 ha**
Watershed Forest Cover (WFC) = **13%**

Legend

- Study Area
- Park and Natural Areas
- Ditch
- Watercourse
- Permanent Streams
- 30 m Riparian Buffers on Permanent Streams
- Existing Forested Areas
- Existing Riparian Areas

Reference: Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.

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Riparian and Watershed Forest Cover

Figure 4-2

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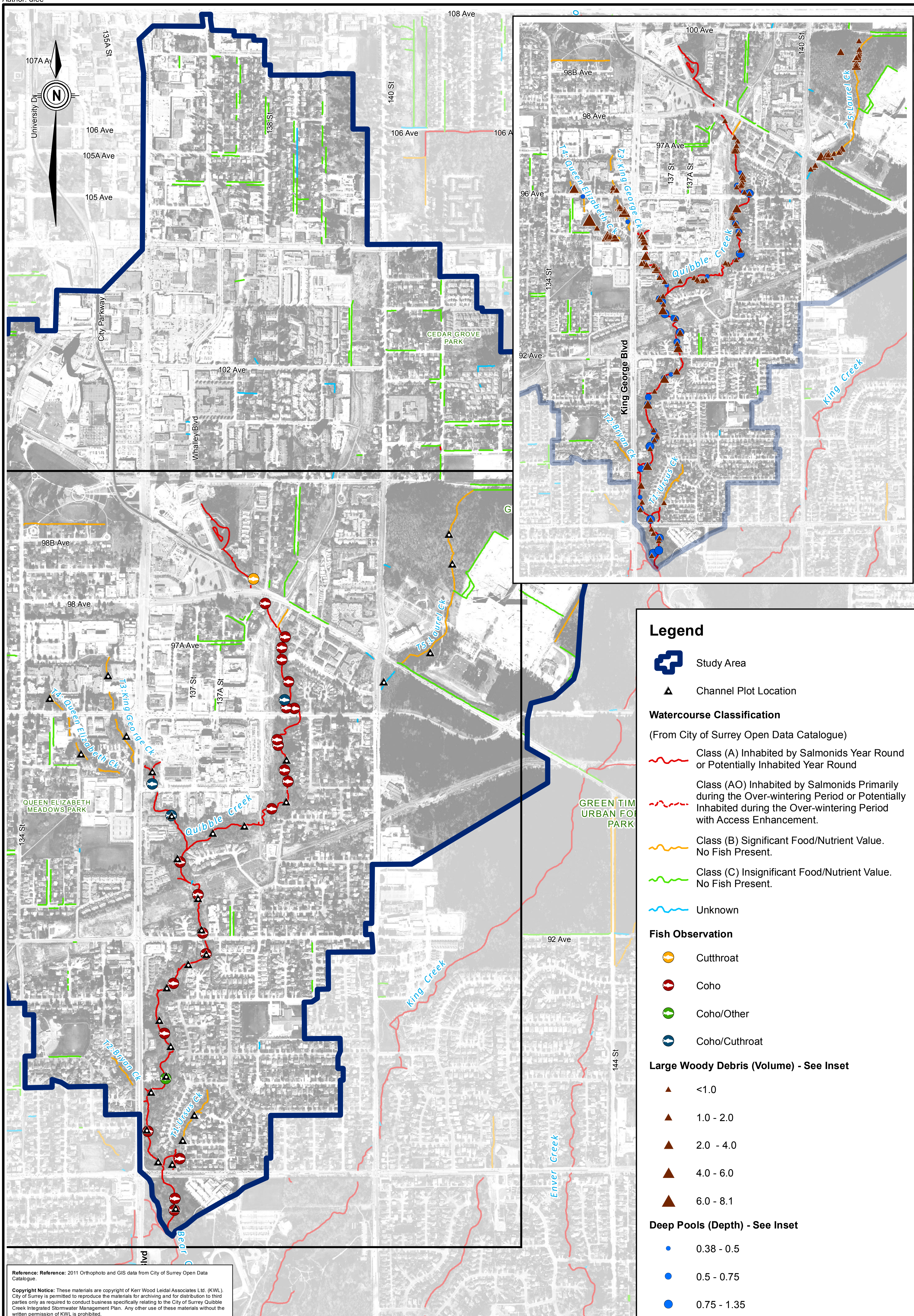

Reference: Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.

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Watercourse Inventory

Figure 4-3

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Section 5

Modelling and Engineering Assessments

5. Modelling and Engineering Assessments

5.1 Introduction

This section outlines the development of the hydrologic and hydraulic model of the Quibble Creek ISMP study area. The model was built using the City's GIS database to assess the existing drainage system under different design event conditions. The results of the analyses are presented in the following subsections.

5.2 Hydrologic and Hydraulic Modelling

Hydrologic and hydraulic modelling using the PC-SWMM software was undertaken for the entire Quibble Creek catchment and drainage system.

The model includes 3,084 urban catchments, 1,788 road catchments, 66 km of storm sewers, 1541 manholes, 1 detention facility, and all the creek channels for Quibble Creek and its tributaries (KGH Tributary, 135 St. Tributary, 142 St. Tributary). See Figure D-7 for the modelled network.

Models were created for both existing and future (unmitigated) land use conditions. The existing conditions model was calibrated and validated using flow monitoring data collected at Quibble Creek at 88th Ave. The flow monitoring station has been in operation and continuously recording data since 1996. Real storm events from 2007 to 2009 were used to calibrate the model. Detailed information on the building of the model and results of calibration can be found in Appendix D.

The impervious coverage for the existing and future land use scenarios are shown in Table 5-1. Effective Impervious Area (EIA) is the impervious cover in the watershed that effectively contributed runoff directly to the storm drainage system as determined during calibration of the Existing Conditions model. EIA for the future conditions scenario must be based on engineering judgement of the predicted increase in total impervious area (TIA) combined with the expected level of hydrologic disconnection in the future conditions scenario.

Table 5-1: Existing and Future Land Use Impervious Coverage

Scenario	Total Impervious Area (TIA) (percent)	Effective Impervious Area (EIA) (percent)
Existing Conditions	67	47
Future Unmitigated Conditions	74	64

5.3 Hydrotechnical Assessment

This subsection outlines the assessment of the drainage system under different design storm events for the existing and future unmitigated land use conditions.

Peak Flow Estimates

The peak flow estimates at the flow monitoring station are summarized in the following tables for existing and future land use conditions.

Table 5-2: Peak Flow Estimates in Quibble Creek at 88 Avenue

Land Use Conditions	Peak Instantaneous Flow Estimate (m^3/s)			
	2-yr	5-yr	10-yr	100-yr
Existing Land Use	8.9	12.8	13.7	17.9
Unmitigated Future Development	14.5	15.7	18.5	20.6

Hydrotechnical Assessment

Minor Drainage System

The entire drainage system was assessed to determine its ability to convey the minor design storm event (5-year return period). The assessments did not include review of storm sewer condition or age. The drainage system was assessed to determine its ability to convey the minor flow, generated by the 5-year return period rainfall event. The following three criteria were used to determine whether each sewer is undersized:

- Modelled instantaneous peak flow is larger than pipe capacity under free-flowing conditions;
- Pipe surcharged for longer than 15 minutes; and
- Water surcharged higher than 0.3 m above the crown of the pipe.

The storm sewers that appear to be undersized and pipes that are surcharged under existing land use conditions are shown schematically on Figure 5-1.

Pipes that have sufficient capacity for existing flows but will need to be upgraded to meet the capacity requirements of the future 5-year flow have also been identified and are shown on Figure 5-2. Proposed upgrades have been sized for the future flow for each pipe that failed the criteria (see Appendix E for existing and proposed pipe sizes).

Smaller pipes and ones at the top end of the system may not need to be upgraded immediately. They can operate under a surcharged condition and as they deteriorate near the end of their design life, they should be replaced with the recommended sizes.

Major Drainage System

The culverts were assessed on their ability to pass the required 100-year peak flow and without flooding the land upstream. Four culverts exceeded the criteria for existing conditions and three culverts exceeded the criteria for future conditions.

Figure 5-3 shows the results from the 100-year existing and future land use conditions models.

5.4 Continuous Simulation

A continuous simulation of the entire watershed was completed using a simplified model to evaluate the effectiveness of best management practices and specifically the application of source controls. Different source controls are selected for different land uses and areas within the watershed based on feasibility of implementation. These source controls will essentially help reduce the effective impervious area. This reduction of effective impervious area forms the basis of meeting the volume capture criteria discussed later in Section 7.

The target effective impervious area for each land use was applied into the hydrologic model for the mitigated future land use scenario (see Appendix D). Two other scenarios were also simulated using the simplified model; one for existing land use conditions and also, one for unmitigated future land use conditions for comparison purposes.

A 10 year period of rainfall was simulated to evaluate the performance of the source controls. Duration exceedance curves were created at the downstream end of Quibble Creek near the outfall to Bear Creek, which show the unmitigated impacts of future development and also the beneficial effects of the source controls at full implementation on the erosive forces in the creek for the entire flow regime. The curves are shown on Figure 5-4.

Detailed information on the hydrotechnical assessment and continuous simulation can be found in Appendix E.

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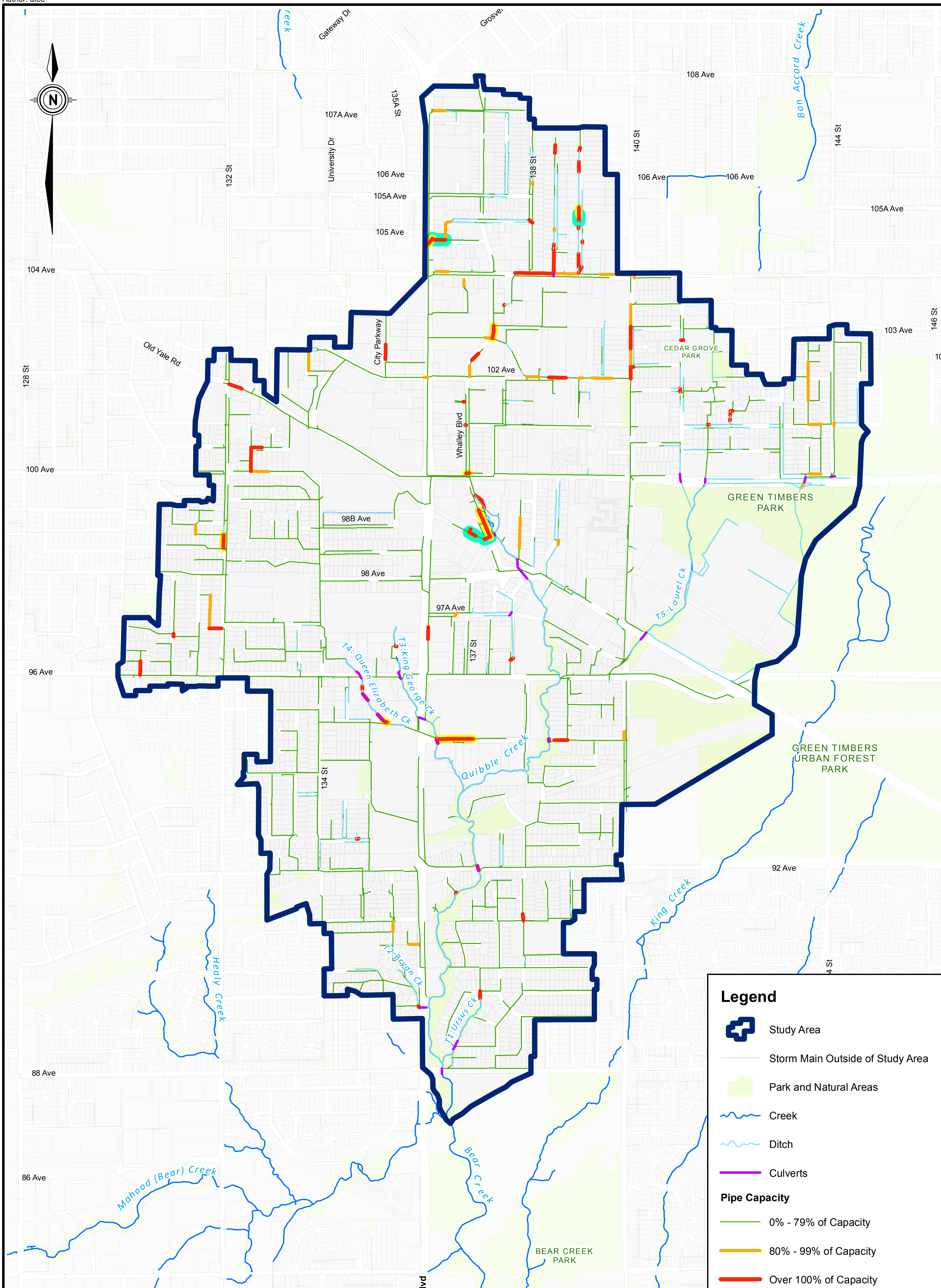

Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

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Project No.	Date
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5-Year Existing Land Use Model Results

Figure 5-1

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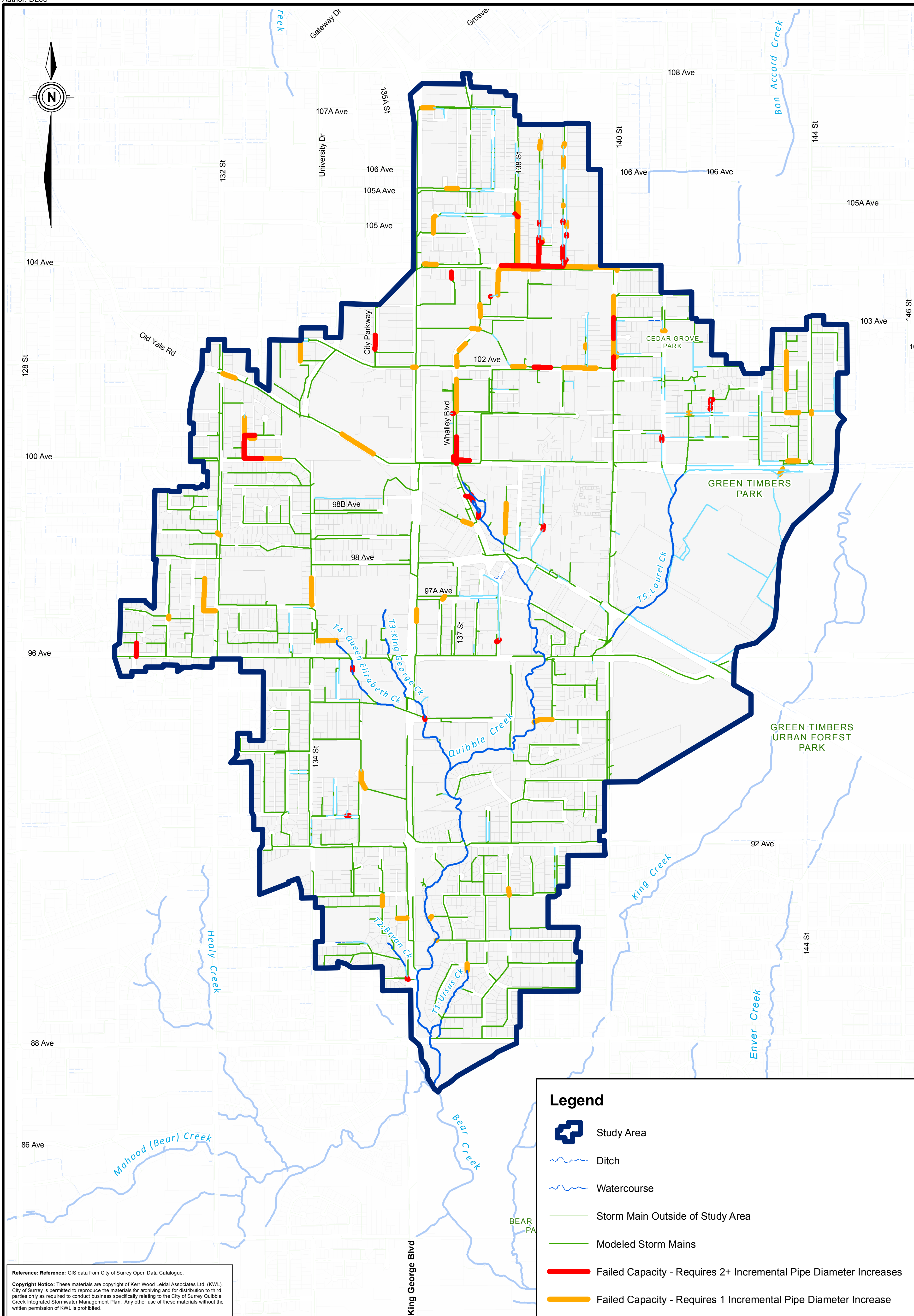

Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

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5-Year Unmitigated Future Land Use Model Results

Figure 5-2

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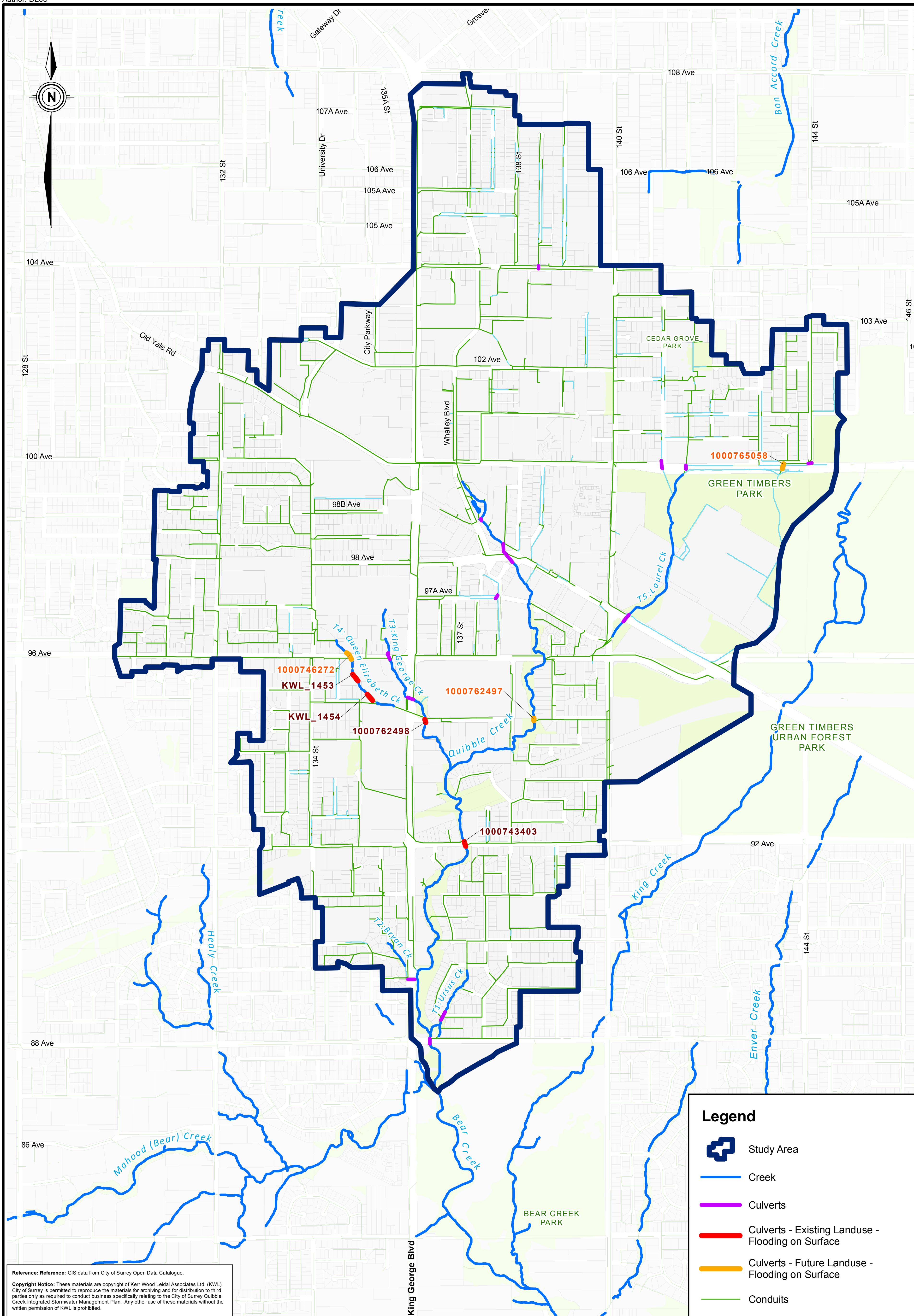

Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

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Quibble Creek Integrated Stormwater Management Plan

Project No.	Date
471-239	February, 2014

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100-Year Existing and Future OCP Land Use Model Results

Figure 5-3

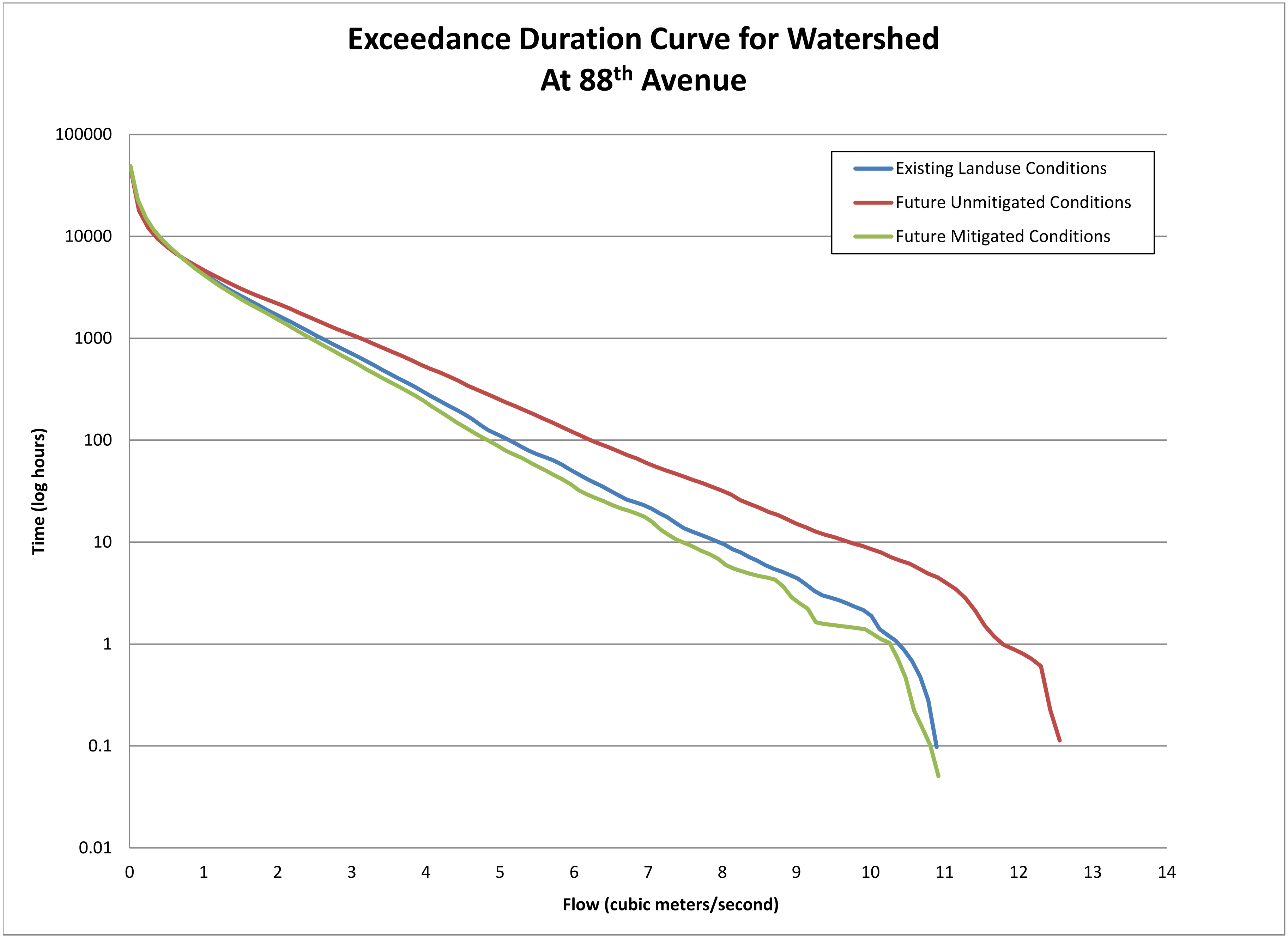

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Figure 5-4

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Section 6

Vision for Future Development

6. Vision for Future Development

A key part of the ISMP process is to establish the vision, goals and criteria for the watershed. During this process the stakeholders begin to take ownership of the ISMP and it becomes a shared mission. To achieve this, two key workshops were held. The objectives, processes, and outcomes of the visioning workshop and the architect meeting, are described in this section.

6.1 Visioning Workshop

The objective of the vision workshop was to establish a vision for the watershed and to establish goals for mitigating the impacts of future development on watershed health.

Surrey City Centre is one of the most significant urban development areas in the province and multiple studies concerning the future of the area have already been conducted including the City Centre Area Plan Update, the City Centre (General Land Use Plan Update) Utility Servicing Study and the Quibble Creek Functional/Feasibility Plan. These studies along with the City of Surrey Sustainability Charter and the Surrey Drainage Policy lay the foundation for the Quibble Watershed Vision. The Vision Workshop was structured to build on the pre-existing goals and objectives.

Multiple stakeholders from the City were invited to participate in a 2-hour workshop. Nine representatives from parks, engineering, and planning departments attended the meeting. The attendees were asked to participate in a series of discussions on the vision for the watershed and on methods for mitigation various impacts of development. Meeting minutes as well as the workshop agenda, and supplementary material are included in Appendix F.

Vision Statement

The vision for the Quibble Creek watershed has three pillars:

1. Quibble Creek remains an essential part of the Surrey's developing City Centre, providing access to nature and educational opportunities for people and significant in-steam and riparian habitat for fish and wildlife.
2. The net health of the watershed is protected and maintained or improved over the long-term, through the building and re-development process.
3. The stormwater infrastructure continues to protect life and property from erosion and flooding.

Each of the three pillars of the vision statement are further described below.

Pillar 1: Quibble Creek remains an essential part of the Surrey's developing City Centre, providing access to nature and educational opportunities for people and significant in-steam and riparian habitat for fish and wildlife.

In order for Quibble Creek to remain a vibrant part of the City Centre, the physical integrity of the creek should be protected and enhanced when possible. In addition to a physical presence in the community, the creek will have a virtual presence through simple initiatives and programs that raise awareness of the creek and the creek's benefits to the community. The following goals from the visioning session help achieve the vision.

- Protect and enhance the riparian area. No development should encroach on the riparian area.
- Protect and enhance salmon habitat in the creek.
- Enhance the quality and increase the connectivity of green 'infrastructure' in the watershed.

- Re-connect disconnected tributaries to improve total stream network and enhance fish habitat.
- Improve recreational access to creek and riparian area with managed access points and promote appreciation without intrusion.
- Involve developers and local residents in project planning, implementation, and monitoring to promote awareness and appreciate for Quibble Creek and its integration into the urban fabric.

Pillar 2: The net health of the watershed is protected and maintained or improved over the long-term, through the building and re-development process

During the visioning session, there was consensus that in the future Quibble Creek should continue to support healthy salmon and other fish populations. A healthy watershed leads to a healthy fish population. In addition to the goals presented above, the following elements are geared towards maintaining or improving the health of Quibble Watershed:

1. Stormwater best management practices (source controls) are incorporated into design of neighbourhoods, roads and buildings (for every new development and redevelopment) to reduce total impervious area in the watershed, decrease connectivity, increase infiltration, and in some instance provide water quality treatment.
2. Promote and incorporate on-site rainwater management (infiltration, reuse and storage of rainwater) into all developments to the maximum practical extent.

Pillar 3: The stormwater infrastructure continues to protect life and property from erosion and flooding.

Protecting communities from flooding is a key function of each ISMP and is a pillar of the vision for Quibble.

- Upgrade failing or undersized stormwater infrastructure and prevent flooding due to increased peak flows from developed impervious area.
- Provide adequate detention on site to maintain post-development flows at pre-development levels.

6.2 Architect Meeting

Following up with the vision workshop, a meeting was held with a group of architects that are working on developments in the Surrey City Centre. The goal of the meeting was to enhance the implementation of the ISMP by involving the architects in the process of selection of Low Impact Development techniques and site level BMPs that will be recommended by the ISMP.

A number of architecture firms were invited and five architects and landscape architects representing four firms were able to attend. The meeting was also attended by representatives from the City's engineering and planning departments. The agenda and minutes are included in Appendix F. Key ideas from the meeting are summarized below.

Showcasing the Quibble Watershed

One of the key ideas from the meeting was that in order for ISMP recommendations to get implemented, residents, developers and other professionals that live and/or work in the watershed need to be aware of Quibble Creek. The attendees suggested that the City raise awareness of Quibble Creek and its unique environmental values through:

- Showcasing the creek as an important asset in the City Centre that provides access to nature.
- Telling stories about the creek in public spaces, on website, at events, etc.

Developers' attitudes towards BMPs

- Developers in Surrey City Centre are open to the idea of BMPs.
- Cost and space requirements are barriers to wide spread use of BMPs by City Centre developers.
- Surface BMPs' aesthetic qualities make them appealing to developers and architects.

Tools, resources, and regulatory support that the City can provide for successful implementation of BMPs

- There is a need for a City enforced stormwater management requirement.
    - There is a need for a stormwater management requirement that each developer has to meet at the edge of the development property.
    - The requirement should be transparent and based on science.
    - The criteria should not be overly prescriptive.
- Consider opportunities with streamlining parks (tree planting) and engineering (stormwater) requirements.
- Offer a tool to help architects and consultants better understand trade-offs of different solutions (stormwater calculator).
- Architects were in favour of incentives but the planning department does not believe that incentives are beneficial. Currently, Engineering does not have an incentive to offer.
- Stormwater issues should be presented at early stages in the design process and in planning documents and bylaws.
- Continuing collaborative workshops where engineers, planners, architects, and City staff can share ideas and best practices will be beneficial.
- Civil Engineers should be involved in development projects at earlier stages. They can identify opportunities and barriers for stormwater management early on. This can be a requirement by the City.

6.3 ISMP Guidance

The information gathered from the visioning workshop and the meeting with architects and City departments provided guidance in the development of the ISMP for the Quibble Creek watershed. The following section describes the ISMP that include recommendations from high level planning such as adopting stormwater criteria to specific projects that will maintain watershed health.

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Section 7

Integrated Stormwater Management Plan

7. Integrated Stormwater Management Plan

7.1 Introduction

The key issues for this ISMP include the following:

Table 7-1: Key Issues in Quibble Creek Watershed

Key Issues
Flood Management • Undersized storm sewers
Erosion Management • Erosion in the stream channels
Mitigation of Future Development/Redevelopment Impacts • Increasing imperviousness in the watershed with new development and re-development
Environmental Protection and Enhancement • Threats to Riparian and Stream integrity

This section discusses the elements necessary to address the key issues of flood management, erosion management, mitigation of the impacts of development and re-development and environmental protection and enhancement.

The solutions are developed in line with the City's Sustainability Charter to minimize environmental impacts of development. The charter cites that the City will demonstrate best practices in sustainable civil engineering by:

1. Reviewing current practices and regulations and removing any unnecessary barriers to the provision of green infrastructure;
2. Implementing sustainable green infrastructure on public land, in public rights-of-way and in private developments;
3. Minimizing environmental impacts of development by re-creating the natural environment to the extent possible in drainage, landscaping, sewer and water projects, and
4. Implementing demonstration projects, including monitoring, refining of future best practices and distributing lessons learned.

The charter also enters into details with respect to enhancing and protecting natural areas, fish habitat and wildlife habitat; these are of critical importance to the Quibble Creek ISMP.

7.2 Proposed Watershed Criteria

The purpose of this section is to review existing criteria set previously for areas in the Quibble watershed and clarify them as required, and to summarize the criteria proposed in this ISMP for the watershed as a whole.

City Centre Criteria

In the *Surrey City Centre General Land Use Plan Update – Utility Servicing* (AECOM 2010) report Table 7-1, a stormwater strategy and performance targets were summarized for the City Centre area. The strategy concludes that source controls or best management practices (BMPs) are a key element in achieving the objectives and performance targets. Table 7-2 below shows the criteria set in that report.

Table 7-2: Stormwater Strategy and Performance Targets for City Centre Area*

Objective	Strategy	Performance Target
1. Adequately service the area to protect life and property	Ensure the drainage system is designed according to the City of Surrey Engineering Department Design Criteria Manual.	As outlined in the Design Criteria Manual
2. Mitigate the adverse impacts of urban runoff water quality on watercourses	Control the flow of pollutants from the larger sources (construction sites and motor vehicles).	TSS < 25 mg/litre
3. Mitigate the adverse impacts of flows and velocities in the watercourse	Control the volume and rate of flow from frequent rainfall events and ensure sufficient base flows in streams.	Volume: Retain 50% of the 2-year storm Flow Rate: Reduce post-development discharge rate to pre-development discharge rate for the 2, 5 and 10 year 24 hour storm.
4. Protect the riparian habitat and support the aquatic life along the watercourses	Stream corridors are protected by setting minimum stream setbacks.	30 metre riparian corridor (e.g. 30 metre from top of bank on either side of the stream) is protected along the entire length of all watercourses.
**Criteria from Surrey City Centre General Land Use Plan Update – Utility Servicing, Report 2 – Stormwater Best Management Practices Strategy* (AECOM 2010).		

The strategy places a strong emphasis on using source controls to infiltrate water back into the ground wherever possible. The 2-year return period, 24-hour duration storm in North Surrey is equal to 64.6 mm of rainfall; 50% of the 2-year, 24-hour storm is equal to 32 mm. There are three priorities identified and each one has a simple calculation linking the amount of infiltration material or storage volume required. The following prioritized approach for addressing volume capture is intended to approximately meet the 32 mm capture criterion. Independent calculations using capture volumes have been performed to verify that when applied correctly, this prioritized approach should meet the intent of mitigating future impacts to flows as they relate to volume reduction.

Priority 1 – Infiltration

In order to meet the volume capture criteria set for the City Centre area, infiltration is the preferred method especially in areas with good soils. The following recommendation is for a required volume of infiltration material based on total site area.

$$\textit{Required Volume of Infiltration Material } (m^3) = (\textit{site area in } m^2) \times 0.5 \textit{ metres}$$

Priority 2 – Evapotranspiration

If runoff from areas cannot be infiltrated into ground, for example, where there are site constraints such as underground parking, there should be a minimum 75 mm of growing medium designed to meet the volume capture criteria. If the vegetated areas are in poor soils, there must be a storage volume to detain flows to meet the rate control criteria.

Required stormwater storage (m^3) = (landscaped area with no infiltration in m^2) x 0.02 metres

Priority 3 – Detention

For areas where runoff cannot be captured via infiltration or evapotranspiration, storage should be provided to detain post-development flows and release at an equivalent rate to pre-development flows.

Required stormwater storage (m^3) = (impervious area in m^2) x 0.05 metres

Assumptions and Conditions for City Centre Criteria

The following section provides further clarification for the City Centre criteria determined in the *Surrey Centre General Land Use Plan Update* (AECOM 2010) report. The prioritized criteria is to be applied on all development to meet the capture criteria overall in the watershed.

Priority 1 - Infiltration

The strategy proposed above will be used to meet the rainfall capture target. The first priority prescribes a volume of infiltration material equal to a 0.5 m depth multiplied by the total site area. This infiltration material can come in the form of low impact development techniques such as pervious pavement, absorbent topsoil, and landscaping growing medium.

Using this equation would result in large infiltration material volumes and excessive depths of infiltration material. For example, a site that is 50% impervious would require that the pervious half of the site accommodate a one meter thick layer of infiltration material. Furthermore, for catchments that are mostly impervious, the footprint area available to place this material would be very small. A limitation on how deep the layer of soil can be placed is necessary to avoid unfavourable capture and infiltration conditions. A deep layer of soil over a small area is not equal to a shallow layer of soil over a larger area given the same soil volume.

It is reasonable to assume that the 0.5 metre layer of infiltration material (topsoil) is placed only on the pervious areas and the impervious surfaces are graded to drain into these areas. To avoid overwhelming the topsoil on the pervious areas, the impervious to pervious ratio should not exceed 2:1. If the impervious area is less than twice the size of the pervious area, then no other action is required as the criterion is met.

Priority 2 – Evapotranspiration

Similarly with the Priority 2 calculated water storage volume for evapotraspiration, adequate footprint has to be provided for plantings to be able to use the stored water. Using a large depth of topsoil with a small footprint could mean that the water stored in the lower depth will not be accessible for uptake by the plants. Furthermore, the small footprint could mean that there simply are not enough plants to evapotranspirate the volume required to meet the capture criterion. Again, additional sizing information is needed.

For roof top planters the maximum soil depth is 1 m and the impervious to pervious ratio should not exceed 10:1. For green roofs, the maximum soil depth is 0.3 m and the impervious to pervious ratio should not exceed 2:1.

Priority 3 – Detention

It is important to attempt to capture the rainfall using infiltration and evapotranspiration measures but if proven inadequate to capture the entire volume, the remaining volume of runoff will determine the size of the detention facility. Example 1 below shows how a detention facility can be sized for the remaining unmitigated impervious surfaces. The release rate should be limited to the predevelopment rate and the detention facility should be able to drain within three days.

The equation provided in the previous section is for impervious areas that are not directed to pervious areas, or covered by planters or a green roof to calculate the required stormwater storage volume. Essentially, this equation provides 50 mm of storage depth for all unmitigated impervious areas.

The following two examples illustrate how the criteria can be achieved in two distinct land uses within the City Centre. The example calculations approximate the 32 mm capture recommended for the Quibble Creek watershed.

Example 1: Commercial/Institutional Calculation in City Centre

Consider a typical commercial lot in the Quibble Creek Watershed assuming:
Area = 0.2 hectares (2,000 m^2) Impervious percentage = 90%
Impervious area = 90% x 2,000 m^2 = 1,800 m^2 Pervious area = 200 m^2
(1,000 m^2 is building roof area and 800 m^2 is pavement)

Priority 1 – Apply infiltration material:
Place 0.5 m layer of infiltration material (topsoil) on the 200 m^2 pervious area and drain a maximum of 400 m^2 of impervious pavement to it.

Priority 1 takes care of the 200 m^2 pervious area and 400 m^2 of impervious pavement. This leaves 1,000 m^2 of roof and 400 m^2 of pavement to be addressed with the next priorities.

Priority 2 – Apply evapotranspiration storage:
Install rooftop planters or a green roof. For the 1,000 m^2 roof area, provide the storage volume as per the Priority 2 equation:
Stormwater volume = Roof area x 0.02m = 1,000 m^2 x 0.02m = 20 m^3 of water holding capacity in planters or green roof.

Priority 2 takes care of the entire 1,000 m^2 roof. This leaves the remaining 400 m^2 of pavement to be addressed with Priority 3.

Priority 3 – Add detention storage:
Calculate the volume required for the runoff from the remaining 400 m^2 of pavement as per the Priority 3 equation:
Stormwater storage volume = 400 m^2 x 0.05m = 20 m^3 of water storage in a detention tank.

The outlet orifice for the detention tank should be sized to release flow at a rate equivalent to the pre-development runoff rate and be able to drain down within three days.

Priority 3 takes care of the 400 m^2 of pavement meaning that now the entire site is accounted for with the three priorities.

Example 2: Single Family Residential Calculation in City Centre

Consider a typical residential lot in the Quibble Creek Watershed assuming:
Area = 0.07 hectares (700 m^2) Impervious percentage = 60%
Impervious area = 60% x 700 m^2 = 420 m^2 Pervious area = 280 m^2

Priority 1 – Apply infiltration material:
Place 0.5 m layer of infiltration material (topsoil) on pervious area.

Check that the impervious area is less than twice the pervious area:
420/280 = 1.5 and therefore confirmed.

Draining the entire 420 m^2 area onto the 280 m^2 pervious area with 0.5m of infiltration material meets the volume reduction criterion. No other action is required.

Quibble Creek Watershed Criteria Outside City Centre

The proposed criteria for the Quibble Creek watershed are summarized below in Table 7-3:

Table 7-3: Proposed Stormwater Criteria for Quibble Creek outside City Centre

Application		Criteria/Methodology
Hydrotechnical Component (Flood and Erosion Protection)	Minor Drainage System	• 5-year return period design event.[1]
	Major Drainage System	• 100-year return period design event[1]
	Agricultural Drainage – ARDSA[1]	• Maintenance of a flood control and drainage system in the lowlands for agriculture in floodplains
Environmental Component (Environmental Protection)	Volume Reduction Source Controls	• On-site rainfall capture (runoff volume reduction) target of 32 mm. • Source controls on single-family, multi-family residential, commercial, institutional, and industrial development and roads to reduce impervious area. 450 mm of absorbent topsoil on all pervious areas and grading hard surfaces to pervious areas on single family development. • Regional facilities to make up for any on-site capture shortfalls.
	Water Quality Treatment	• Collect and treat 80% of annual runoff from impervious areas with BMPs. • Design water treatment facilities to meet the maximum allowable total suspended solids (TSS) of 25 mg/L [2]
	Watercourse Erosion Prevention/ Rate Control	• Control 5-year post-development flows from development site to 50% of 2-year post-development flow.[1] OR • Control 5-year post-development flow to 5-year pre-development flow rate.
	Riparian	• Establish riparian setbacks to comply with *Riparian Areas Regulation*[3] and the City of Surrey's Ecological Management Study and the recommendations from the Biodiversity Plan.

1. City of Surrey Design Criteria Manual, May 2004.
2. British Columbia Water Quality Criteria for Aquatic Life.
3. DFO Urban Stormwater Guidelines and BMPs for the Protection of Fish and Fish Habitat, 2001.

The same three priority approach to meeting the volume reduction target should be applied outside of the City Centre as shown in the previous section.

7.3 Flood Management

Historically, flooding records within the study area do not indicate a widespread problem of major flooding. As Quibble Creek outlets into Bear Creek at Bear Creek Park, there also isn't a large lowland area that is prone to flooding due to downstream backwater conditions. Potential localized flooding within the study area would most likely be attributed to heavy rainfall and clogged catch basins or undersized storm sewers. Two areas were identified at the onset of this study by City staff: 100th Avenue and Whalley Boulevard and, along Old Yale Road.

Undersized storm sewers and culverts were identified in Section 5. Pipe upgrades are evaluated and prioritized in the capital upgrades program in Section 7.8. Pipe upgrade sizes are based on future unmitigated flows because of the following assumptions:

- Not all detention may be implemented on site;
- Provides a factor of safety; and,
- Accommodates potential failure of detention facilities (e.g. clogged orifice, sediment accumulation etc.).

Before a pipe is upgraded to the recommended size, during the detailed design where more site specific information is known, the design flow and pipe size may need to be refined.

7.4 Erosion Management

The drainage inventory noted a number of areas of erosion and channel obstructions in the creek system. Erosion is a naturally occurring process and may not be a serious issue for every instance. The areas that are away from property or infrastructure may not warrant repair as these sites pose low to no risk of damage. Nevertheless, these sites should be monitored for park maintenance efforts and any potential downstream effects.

Embankment Repair

In areas where erosion is severe and there is an imminent threat to impact infrastructure or property, embankment repair and structural protection of the eroding stream banks may be more favourable than relying on only preventative measures. Two sites were identified as high risk:

- Site ID 147.49 – Quibble Creek 142 St. Tributary: erosion of creek bank on both sides of a concrete culvert, hydro pole is being undercut and at risk of falling on the roadway; and
- Site ID 147.55 – Quibble Creek KGH Tributary: undercutting of a tree and the surrounding bank, tree is leaning towards and is at risk of causing damage to a new housing development.

Possible embankment repair projects would involve:

- Accessing the creeks with equipment;
- Re-constructing the banks where required; and
- Stabilizing the creek banks with bio-engineering (if possible) or structural revetment (e.g. stone riprap, loc-block wall, concrete, etc.).

Embankment repair is likely the most cost-effective approach for the specified erosion sites. However, environmental agencies (DFO, MOE) are not always supportive of creek armouring or embankment repair projects and the agency approvals might be significant obstacles for such projects to overcome.

Detention Facilities

Detention of flows above locations of erosion in creeks can reduce the rate of erosion caused by frequently occurring flows. The City currently has a bylaw to limit 5-year post-development flows to 50% of the 2-year post-development rate or to the 5-year pre-development rate. In a fully developed watershed such as the Quibble Creek ISMP study area that includes City Center, above-ground regional detention is a difficult solution to implement because there is generally very little available land.

With the adoption of the stormwater criteria and implementation of source controls to mitigate the impacts of future developments, municipal regional detention facilities are becoming a less favourable solution to rainwater issues. Historically, detention facilities are used to limit peak flows for flood and erosion management. Based on the City's historical flooding records indicating only two localized flooding problem areas at 100th Avenue and Whalley Boulevard and, along Old Yale Road (ie. flooding due to site specific conditions as opposed to watershed wide) and the erosion assessment indicating two high risk sites, implementing municipal detention facilities is not recommended.

In the *Quibble Creek Functional Feasibility Plan* (Earthtech 2001), two ponds, one including a diversion trunk, were recommended. After analysis of the City's current regional detention facilities in the Quibble Creek watershed, the recommended ponds have not been constructed. However, a pond at 100 Avenue and Whalley Boulevard has been constructed mainly for water quality and fish habitat purposes.

In Section 7.2, criterion for detention is applicable to all parcels and the City should check that new developments or redevelopment projects comply with the criteria at the development permit stage.

7.5 Mitigating the Impacts of Future Development Alternatives

In order to maintain the ecological health of the Quibble Creek watershed, and improve over the long-term in accordance with the ISMP goal, the watershed must have a plan for mitigating the hydrologic and environment impacts due to proposed development and redevelopment.

Recommended Source Controls

Based on the outcome of the visioning process, the primary tool for mitigating the impacts of future development is the use of source controls for all developments and re-developments within the Quibble Creek watershed. Appendix G provides background and an overview of low impact development and source control technologies.

To arrive at the recommendations, the project team generated and mapped possible opportunities for source control implementation throughout the watershed and presented these conceptual solutions in the visioning workshop and the architect meeting (described in Chapter 6). Based on the feedback obtained during the workshops, a number of source controls were selected for a more detailed evaluation. At this stage, careful studies of different land use categories were conducted to determine possible levels of redevelopment for each category. Outside the City Centre, development is mostly expected to occur through infilling of residential areas. Within the City Centre, significant land use conversions are anticipated. Based on aerial photos provided by the City and future land use maps from either the OCP (for outside the City Centre) or the Surrey City Centre Neighbourhood Plan, the team evaluated the suitability of each BMP type for different types of development. The factors considered in evaluating the BMPs included the change in impervious coverage of a site, present and future building type (height and footprint), present and future building coverage, parking scenarios, and intended use of future development.

Source control recommendations are developed for different land uses. The recommendations are summarized in Tables 7-4 and 7-5. Table 7-4 addresses the land uses within City Centre and Table 7-5 provides recommendations for the area outside the City Centre. Land uses and soil types are shown on Figure 7-1. Appendix G shows details of roadside bump out rain gardens that are primarily recommended for Collector Roads within the City Centre but could also be used for other road classes.

Source controls need to be sized not only for the capture target, but also to handle the pollutants that come with impervious runoff. Minimum source control sizes relative to the impervious tributary area are often recommended to account for pollutants and long term viability of the source controls. These minimum sizes are documented in the 2012 Metro Vancouver *Stormwater Source Control Design Guidelines* (SSCDG).
http://www.metrovancouver.org/services/wastewater/sources/Pages/StormwaterManagement.aspx

7.6 Environmental Compensation and Enhancement Works

The following restoration and enhancement opportunities were identified that focus on four components:

1. Landscape-level connections including forest protection or restoration that support the City's green infrastructure network as well as watershed-scale functions;
2. Riparian restoration and management that focuses on increasing the amount and ecological function of riparian forest;
3. Instream and off-channel habitat restoration to enhance fish populations; and
4. Fish passage improvements to restore access to habitat.

Priority actions are described below and locations are shown in Figure 7-2.

Watershed and Landscape-scale Actions

The Green Infrastructure Network analysis identified Green Timbers Urban Forest and Bear Creek Park as important large natural areas (hubs) in north central Surrey with connections through King Creek and other corridors. Quibble Creek was considered a local (secondary corridor) because it is longer and more discontinuous than King Creek. However, the Quibble Creek corridor has substantial connectivity values that can be enhanced through land acquisition, forest planting, and other actions. The utility corridor (see local corridor 116 on Image 4-1) is also important for east-west connectivity to Green Timbers.

Challenges to increase non-riparian forest cover include the existing high level of development, limited park space, and vegetation management constraints on the utility corridors. The integrity of the existing forested riparian corridor offers limited opportunity for substantial gains through reforestation.

The eastern side of the watershed between 92 Ave and Fraser Highway was identified as an important area for improving landscape-level connectivity. Tree retention during redevelopment, active tree planting or garden naturalization, street closure or narrowing and park acquisition (as small as single lots) should be emphasized in these areas. Figure E-23 shows the general boundary of this area and identifies several small forest patches that should be protected during redevelopment.

Table 7-4: Suggested BMPs for Quibble Watershed Within Surrey City Centre

	Land Use	Projected Building Type	Projected Future Unmitigated TIA[1]	Suggested BMPs	Timeline for Implementation
A	Single Family/Duplex 0.6 FAR	Existing One or Two Family Dwelling	75%	▪ Provide 450 mm absorbent soils depth on all grassed and landscaped areas ▪ Disconnect roof leaders and direct to absorbent landscape	Ongoing
B	Low to Mid Rise up to 2.5 FAR, Mixed-Use 2.5 FAR	Residential, Townhouses	90%	▪ Provide 450 mm absorbent soils depth on all grassed and landscaped areas ▪ Use pervious pavers for walkways, driveways, and surface parking ▪ Direct roof and any other pavement runoff to subsurface infiltration facilities or rain gardens (well-draining soils only) ▪ Detention tank (poorly-draining soils) ▪ Install a storage tank for capture of roof water. Water to be piped for re-use through a "purple pipe" to toilet facilities (poorly draining soils, optional for well-draining soils)	1-10 years
C	Mid to High Rise up to 3.5 FAR; High Rise 5.5 FAR; Mixed-Use 3.5 FAR; Mixed-Use 5.5 FAR; Mixed-Use 7.5 FAR	Residential, Commercial and Mixed Use Low Rise to High Rise Buildings	80% - 90%	▪ Provide 450 mm absorbent soils depth on all grassed and landscaped areas ▪ Use pervious pavers for walkways, driveways, and surface parking ▪ Direct roof and any other pavement runoff to subsurface infiltration facilities (well-draining soils only) ▪ Detention tank (poorly-draining soils) ▪ Install a storage tank for capture of roof water. Water to be piped for re-use through a "purple pipe" to toilet facilities (poorly-draining soils, optional for well-draining soils) ▪ Install green roofs on 4-6 stories commercial buildings (poorly-draining soils, optional for well-draining soils)	1-10 years
	School; Institutional; Plaza		75% (School & Institutional) 90% (Plaza)	▪ Provide 450 mm absorbent soils depth on all grassed and landscaped areas ▪ Use pervious pavers for walkways, driveways, and surface parking ▪ Direct roof and any other pavement runoff to subsurface infiltration facilities or rain gardens (well-draining soils only) ▪ Detention tank (poorly-draining soils) ▪ Install a storage tank for capture of roof water. Water to be piped for re-use through a "purple pipe" to toilet facilities (poorly draining soils, optional for well-draining soils)	1-10 years
D	Park; Creek Buffer; Greenway		10%	▪ Direct impervious runoff onto pervious areas	Ongoing
E	Road; Long-term Road		80%	▪ Direct road runoff to bump out rain gardens for new collector roads (see Appendix G for details. ▪ Direct road runoff to subsurface infiltration facilities for all other road types.	1-10 years

Notes:
[1]TIA = Total Impervious Area expressed as a percentage of total lot area. Numbers in this column are estimates for future development.
Well-draining and poorly draining soils in the context of this ISMP are defined in Section 2.3.

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Table 7-5: Suggested BMPs for Quibble Watershed Outside Surrey City Centre

Land Use		Projected Future Unmitigated TIA[1]	Max Allowable Lot Coverage[2]	Suggested BMPs	Timeline for Implementation
A	Single Family Residential	75-80%	40-50%	▪ Provide 450 mm absorbent soils depth on all grassed and landscaped areas ▪ Disconnect roof leaders and direct to absorbent landscape	Ongoing
A	One Acre Residential	35%	20%	▪ Provide 450 mm absorbent soils depth on all grassed and landscaped areas ▪ Disconnect roof leaders and direct to absorbent landscape	Ongoing
B	Duplex & Multi-Family Residential	75% (Duplex); 90% (Multi-Family Residential)	33% (Duplex); 45% (Multi-Family Residential)	▪ Provide 450 mm absorbent soils depth on all grassed and landscaped areas ▪ Use pervious pavers for walkways, driveways, and surface parking ▪ Direct roof and any other pavement runoff to subsurface infiltration facilities or rain gardens (well-draining soils only)	1 – 10 years
B	Comprehensive Development/ Mixed Use	90%	Undefined	▪ Provide 450 mm absorbent soils depth on all grassed and landscaped areas ▪ Use pervious pavers for walkways, driveways, and surface parking ▪ Direct roof and any other pavement runoff to subsurface infiltration facilities or rain gardens (well draining soils only)	1 – 10 years
C	Commercial (Tourist Accommodation Zone, Child Care Zone, Local Commercial Zone)	75% - 90%	40% - 50%	▪ Provide 450 mm absorbent soils depth on all grassed and landscaped areas ▪ Use pervious pavers for walkways, driveways, and surface parking ▪ Direct roof and any other pavement runoff to subsurface infiltration facilities or rain gardens (well-draining soils only)	1 – 10 years
C	Commercial (Community Commercial; Downtown Commercial)	90%	50% - 85%	▪ Provide 450 mm absorbent soils depth on all grassed and landscaped areas ▪ Use pervious pavers for walkways, driveways, and surface parking ▪ Direct roof and any other pavement runoff to subsurface infiltration facilities (well-draining soils only) ▪ Detention tank (poorly-draining soils)	1 – 10 years
C	Institutional (Assembly Hall Zones)	90%	45%	▪ Provide 450 mm absorbent soils depth on all grassed and landscaped areas ▪ Use pervious pavers for walkways, driveways, and surface parking ▪ Direct roof and any other pavement runoff to subsurface infiltration facilities or rain gardens (well-draining soils only)	1 – 10 years
D	Park, Creek Buffer, Greenway	10%	n/a	▪ Direct impervious runoff to pervious areas	Ongoing
E	Road	80%	n/a	▪ Direct road runoff to bump out rain gardens (see Appendix G for details) or linear rain gardens.	1 – 10 years

Notes:
[1]TIA = Total Impervious Area expressed as a percentage of total lot area. Numbers in this column are estimates for future development.
[2]Maximum coverage by structures expressed as a percentage of total lot area as specified in Surrey Zoning Bylaw.
Well-draining and poorly draining soils in the context of this ISMP are defined in Section 2.3.

Enhanced park acquisition should be considered for protecting remaining forested areas in the Quibble Creek watershed with emphasis on the eastern side.

Four park areas totalling 2.2 ha were identified for reforestation in non-riparian areas, both as a means to increase ecological value and to restore hydrological functions provided by tree vegetation and forest soils over the long term (see Figure 7-2). These reforestation opportunities are conceptual and require more analysis to identify potential conflicts with current or future recreation uses and other values.

Riparian Corridor Actions

There are limited opportunities to increase riparian forest cover mainly because the existing corridor is well-developed and surrounded by existing residential or institutional land use. Opportunities for additional riparian protection may occur during redevelopment and we recommend that riparian corridors larger than Riparian Areas Regulation (RAR) standards be required during redevelopment along the Quibble Creek corridor. Setback widths of a minimum of 30 m from the active stream channel are needed to preserve stream health and biodiversity in heavily urbanized watersheds such as Quibble Creek. Opportunities to purchase riparian properties should be evaluated as they arise with the long-term goal of increasing the amount of protected area along the Quibble Creek mainstem.

Riparian restoration opportunities include:

- Six sites totalling 1.5 ha were identified for reforestation within the Quibble Creek riparian corridor. The largest site (1.1 ha) is located in Bear Creek Park (see Figure 7-2). Riparian reforestation costs are estimated to be $120,000 per hectare.
- Additional sites (not shown on map) were identified for invasive species management including control of Himalayan blackberry, English ivy, yellow lamium, and Japanese knotweed. Costs are variable but are estimated to be $25,000 per hectare.
- Localized areas of recreation-related disturbance should also be addressed through trail relocation or closure, fencing, signs, and other strategies.

Instream and Floodplain Actions

Seven instream habitat restoration sites (stream segments) totalling 835 m of channel were identified based on existing channel conditions and access to the stream channel for restoration. Specific sites were identified based on channel conditions and access. Suitable techniques include large wood or wood clusters where flood risk is minimal, and boulder groups where there is a risk to infrastructure if large wood is used.

The target for instream enhancement should be to increase the amount of instream wood from 3.2 pieces per 100 m to 5 pieces per 100 m by 2025. This would require the addition of about 120 pieces of wood at a cost of around $240,000 ($2,000 per piece average).

There are also limited opportunities for the creation of off-channel (floodplain) habitats such as ponds, channels, and wetlands because of shallow ravine topography (three potential sites were identified totalling 0.26 ha).

Fish Passage Improvements

Most of the fish passage issues are difficult to address because they will require substantial infrastructure change with relatively little benefit. Recommended actions include:

- Removal of the 33 m culvert at the mouth of Ursus Creek (see Figure 7-2) to restore fish access to the lower 95 m of this small stream (estimated cost: $120,000).
- Replacement of the culvert on the Quibble Creek main stem under 94A Ave (greenway trail) with a clear-span bridge (see Figure 7-2). This culvert does not restrict adult fish migration but likely limits the upstream movement of juvenile fish under low summer flows (estimated cost: $250,000).
- Assessment of opportunities to address culvert barriers at King George Creek and Laurel Creek tributaries over the long term as part of infrastructure renewal.

7.7 Potential Regional Water Quality Facilities

For areas that do not have source controls or do not meet the water quality treatment criteria, regional water quality facilities such as oil and grit separators should be considered.

Figure 7-3 shows the location of potential regional water quality treatment facilities located in hydro ROWs and the catchment areas draining to them.

7.8 Capital Cost Estimates and Funding Strategies

Table 7-6 summarizes the ISMP elements and includes cost estimates and indication of responsibility.

Cost Estimate Assumptions

The cost estimates for the proposed capital works is of Class D accuracy. This means that the general requirements for upgrading including size and approximate depth of excavation, as well as some general site conditions are known. The projects identified have not considered the following factors that may affect construction:

- Relocation of adjacent services (water, hydro, etc.);
- Special permitting requirements (fisheries windows, contaminated sites, etc.);
- Geotechnical issues requiring special construction such as pile-supported piping, buoyancy problems or rock blasting; and
- Critical market shortages of materials.

Surveys and more detailed assessments of proposed capital works should be conducted prior to construction.

Table 7-6: Summary of Quibble Creek Watershed ISMP

Application		Preferred Mitigation Method	Estimated Timeline	Responsibility	Estimated Cost (Class D)
Hydrotechnical Actions (Flood and Erosion Mitigation)	Major Drainage System	• Construct Priority 1 hydrotechnical upgrades see Appendix H)	• 0-5 years	• City	• $1,920,000
	Minor Drainage System – Existing	• Construct Priority 2 & 3 hydrotechnical upgrades (see Appendix H)	• 6-10 years	• City	• $270,900
	DCC Projects	• Construct Priority 4, 5 & 6 hydrotechnical upgrades (see Appendix H)	• Long term, as re-development occurs. Priority 6 upgrades at end of service life.	• Developers	• $2,757,800
	Erosion Management	• Complete remedial slope stability and erosion protection to protect nearby property for locations: Site ID 147.49 – Quibble Creek 142 St. Tributary and Site ID 147.55 – Quibble Creek KGH Tributary.	• Immediate action is recommended.	• City	• $400,000 (allowance)
		• Conduct annual inspections for the other medium risk sites (see Table B-1).	• Bi-Annually (coordinate with Ravine Stability Assessment)	• City	• $50,000 (annual allowance)
Environmental Actions (Environmental Protection and Restoration)	Volume Reduction Source Controls	• Source controls are to be applied on multi-family, neighbourhood attached residential, commercial, institutional, industrial development and roads to capture 50% of the 2-year 24-hour storm (32.3 mm depth) for volume reduction purposes.	• Long-term, as re-development occurs.	• Developer	• Approx. $100,000 - $150,000 per ha of development
		• For single family developments, 450 mm of absorbent topsoil is to be applied on all pervious areas, and impervious areas graded to direct runoff to pervious areas.	• Long term, as re-development occurs.	• Developer	• Approx. $7,500 per lot
	Water Quality Treatment	• Source controls provide water quality treatment through volumetric reduction, for areas that do not have source controls or do not meet the water quality treatment criteria, regional facilities such as oil and grit separators are to be installed.	• Long term, as re-development occurs.	• Developer	• $200,000 per oil/grit separator
	Detention / Diversion Rate Control	• Use on-site detention to control 5-year post-development flows from development site to 50% of 2-year post-development flow OR control 5-year post-development flow to 5-year pre-development rate	• Long term, as re-development occurs.	• Developer	• Varies
	Watershed and Landscape-scale Actions	• Four potential new park areas totalling 2.2 ha identified for reforestation and habitat protection in non-riparian areas.	• Long term.	• City	• Market land rates
	Riparian Protection and Enhancement	• Re-establish riparian corridor and reforest beyond the RAR setback for areas where development encroaches into setbacks of 30 m on each side of the creek. Opportunities to purchase riparian properties beyond RAR setbacks should be evaluated as they arise.*	• Long term, as re-development occurs in encroached areas.	• City + Landowners	• Market land rates
		• Six sites totalling 1.5 ha identified for reforestation within the Quibble Creek riparian corridor. The largest site (1.1 ha) is located in Bear Creek Park.	• Long term, as re-development occurs.	• City	• $120,000 per ha
		• Remove invasive species including control of Himalayan blackberry, English Ivy, yellow lamium and Japanese knotweed.	• Ongoing and long-term	• City	• Varies ($25,000 per ha) plus revegetation
	Fish Habitat Restoration and Passage Improvements	• Complete list of recommended projects (Table 7-4) as needed for fish habitat compensation, to improve environmental values by restoring or enhancing biodiversity and fish habitat.	• Long term.	• City/Developer	• Varies
		• Restoration of instream habitat at seven sites totalling 835 m of channel, increase the amount of instream wood from 3.2 pieces per 100 m to 5 pieces per 100 m.	• Long term.	• City	• $185,000
		• Removal of culvert at the mouth of Ursus Creek to restore fish access to the lower 95 m of this small stream.	• Long term.	• City	• $150,000
		• Replacement of the culvert under 94A Ave (greenway trail) with a clear span bridge	• Long term.	• City	• $250,000

Notes:
*Should not have to buy RAR setback land, only any extra beyond RAR setback if required.

Capital Cost Summary

Flood Management

Detailed tables are in Appendix H and the costs for each priority are summarized in Table 7-7 below.

Table 7-7: Storm Sewer Upgrades Capital Costs

Priority	Cost ($)
1 – Major System, Flooding on Surface, Existing 100-Year Analysis	1,920,000
2 – Minor System, Flooding on Surface, Existing 5-Year Analysis	52,100
3 – Minor System, Surcharge > 15 min and .3 m, Existing 5-Year Analysis	218,800
4 – Major System, Failed Pipe Capacity, Future 100-Year Analysis	208,500
5 – Minor System, Two Incremental Dia. or More Upgrade, Future 5-Year Analysis	875,200
6 – Minor System, One Incremental Dia. Upgrade, Future 5-Year Analysis	1,675,000
Flood Management Capital Upgrades Program Total	**$4,948,600**

Erosion Management

The following sites are identified as high risk and immediate action is recommended and included in the capital plan.

Table 7-8: Erosion Management Capital Costs

Site ID	Description of work	Cost Allowance ($)
147.49 – Quibble Creek 142 St. Tributary	Reconstruct banks around concrete culvert, stabilize Hydro pole	$200,000
147.55 – Quibble Creek KGH Tributary	Stabilize banks around tree and remove leaning tree if necessary	$200,000
Erosion Management Capital Costs Total		**$400,000**

Additional biannual inspections (as part of City's biannual Ravine Stability Assessment) are recommended for the remaining medium risk sites. If after inspection the site is deemed to have degraded to a high risk site, remedial work to stabilize embankments may be required to mitigate erosion concerns.

Environmental Protection and Enhancement

The following sites are for fish passage improvements that included sufficient information for a Class D cost estimate.

Table 7-9: Environmental Protection and Enhancement Capital Costs

Site ID	Description of work	Cost ($)
Ursus Creek culvert	Remove culvert at mouth of Ursus Creek to restore fish access	$120,000
Quibble Creek at 94A (greenway trail) culvert	Replacement of the culvert under 94A Ave (greenway trail) with a clear-span bridge. This culvert does not restrict adult fish migration but likely limits the upstream movement of juvenile fish under low summer flow	$250,000
Environmental Protection and Enhancement Capital Costs		**$370,000**

Estimated unit rate costs for other environmental protection and enhancement works such as reforestation or removal of invasive species are provided in Table 7-9 above.

Funding Strategy

The following section discusses potential funding sources for the capital works, operations and maintenance and education strategies as recommended in the ISMP.

Developer/Development Cost Charges

As the watershed redevelops over time, funds can be collected from developers as part of meeting conditions of the ISMP. The engineering and construction costs are paid by the developer in implementing the solutions to meet the criteria.

The City of Surrey has had Development Cost Charges (DCCs) since 1979 and are used to fund the costs to provide city services such as roads, drainage, water and sewer based on projected growth. These charges are to provide way for the City to continue to expand without overloading the existing infrastructure. In addition to traditional “grey” infrastructure requirements, recommended improvements such as source controls and other green infrastructure can be considered in determining appropriate rates. Only items classified as an asset, such as storm sewers, culverts, bank stabilization, WQ treatment structures etc. can access DCC funds; general planting or aesthetic upgrades cannot.

Stormwater Utility

The City currently imposes a drainage parcel tax under *Bylaw No. 14593* for the entire municipality. The funds collected under the drainage parcel tax are used to construct and operate storm drainage systems. The tax is a flat fee and the rates are described in Schedule A of the bylaw; ranging from $123 to $198 per parcel per year.

Other municipalities across Canada are looking into creating a utility for stormwater infrastructure. Currently, the City of Victoria is in the final process of implementing the stormwater utility. Instead of charging a flat fee, the City of Victoria is using impervious percentage as the main factor in determining the rate per parcel. By basing the fee on impervious percentage, it provides residents and businesses a practical reason to limit the amount of impervious surfaces on the site. It also creates the opportunity for incentives for residents and businesses to implement source controls.

Other Funding Sources

Building Canada Plan – Infrastructure Canada

A new Building Canada Plan is set to begin in 2014-2015 and will provide federal funds to provinces, territories, and municipalities over the next 10 years. The plan includes the Gas Tax Fund, giving municipalities greater flexibility to spend federal funding on a broader range of infrastructure priorities.

Additional information: http://www.infrastructure.gc.ca/plan/plan-eng.html

Green Municipal Fund – Federation of Canadian Municipalities

This fund provides funds for three types of environmental initiatives: plans, studies and projects. The funding is allocated into five sectors of municipal activity: brownfields, energy, transportation, waste and water. All municipal governments and their partners in eligible projects have access to the funding. Below-market rate loans usually combined with grants are available to implement capital projects.

Additional information: http://www.fcm.ca/home/programs/green-municipal-fund.htm

EcoAction Community Funding Program – Environment Canada

This program encourages completion of projects that will protect, rehabilitate or enhance the natural environment. The program supports projects that address the following:

- Clean air: to reduce emissions that contribute to air pollutants;
- Clean water: to divert and reduce substances that negatively affect water quality or to focus on water conservation and efficiency;
- Climate change: to reduce greenhouse gas emissions that contribute to climate change or to deal with the impacts of climate change; and,
- Nature: to reduce biodiversity loss, protect wildlife and plants, and protect and improve the habitat where they live.

The funding is available for non-government, non-profit groups and organizations.

Additional information: www.ec.gc.ca/ecoaction

Evergreen Foundation (multiple programs)

The RBC-Evergreen Watershed Champions Award

This grant provides funding for school programs designed to teach students in publicly funded schools about their local watershed or about water in the context of their local watershed. Classes that provide participation in other watershed or water based programs through local outdoor education centres, conservation authorities, community groups, non-profit organizations and/or government programs are also eligible to apply.

Additional information: http://info.evergreen.ca/en/watershed-champions/award

Walmart-Evergreen Green Grants

Walmart Canada and Evergreen have partnered to offer this funding for community based initiatives across Canada. The amount of the grant is up to $10,000 (up to 50% of the project budget). Projects supported through the Green Grants program include, but are not limited to:

- native planting initiatives;

- invasive species remova;
- community food gardens;
- youth-based and intergenerational projects;
- wildlife habitat restoration;
- aquatic stewardship projects;
- environmental workshops and educational events;
- community skills sharing workshops; and,
- projects serving underserved communities.

The funding is available for groups working collaboratively with a local municipality and the project must be on publicly accessible lands.

Additional information: http://www.evergreen.ca/en/funding/grants-available/green-grants/

Toyota Evergreen Learning Grounds School Ground Greening Grants

The purpose is to help schools create outdoor classrooms to provide students with a healthy place to play, learn and develop respect for nature. This grant is available for publicly funded and accessible schools up to $3,500 for schools and $2,500 for daycares. Eligible expenses include: native plant species, heritage berries, vegetable seeds and plants, tools, materials and professional services.

Additional information: http://www.evergreen.ca/en/funding/grants-available/school-ground-greening-grants/

TD Friends of the Environment Foundation

Founded in 1990, the TD Friends of the Environment Foundation is a national charity that funds environmental projects across Canada. The unique organizational structure allows dollars donated in a community to be directly invested in environmental programs in that community. Grants are available for organizations such as:

- registered Canadian charities with a Chartiable Registration Number (CRN);
- educational institutions (primary/secondary/post-secondary);
- municipalities; and,
- aboriginal groups.

Eligible projects include:

- environmental education;
- tree plantings (native plant species);
- energy conservation;
- schoolyard or urban naturalization projects;
- community gardening programs;
- habitat restoration;
- endangered species/wildlife protection;
- environmental research.

7.9 Approval Procedure and Enforcement Strategy

This section outlines the approval procedure and enforcement strategy for incorporating the ISMP requirements at time of development and re-development.

Departmental Responsibilities

It is important that all departments dealing with development and land use change permitting be aware of the requirements set forth in this ISMP to protect people, property, and the environment while allowing development to occur. Communication between departments is key. Appointment of an in-house Rainwater Management Champion to lead and facilitate interdepartmental communication, coordination and change would be useful. The following responsibilities have been identified:

Planning and Development

- Provide information for developers.
- Check that development plans and designs meet ISMP requirements.
- Inspect source controls during construction as part of the plumbing and lot grading inspections.
- Revise zoning bylaws to accommodate source controls on lots.
- Revise land use plans and council policies to incorporate wider (30m) riparian setbacks.

Engineering

- Modify drainage by-laws to incorporate source controls. Update Engineering design standards for on-lot source controls and standard road cross sections with source controls.
- Implement drainage upgrades and erosion remediation as listed.
- Monitor watershed response to development as per the Adaptive Management Framework.
- Revise ISMP criteria/requirements to adapt to observed changes.
- Complete fish habitat and passage improvement projects as listed.

Parks, Recreation, and Culture

- Investigate four new park areas as recommended (pending approval from Parks department).
- Provide riparian reforestation in Bear Creek Park and other sites as recommended.
- Incorporate drainage source controls in City parks.

General

- Develop an invasive species removal program.
- Develop outreach and education programs.

Proposed Bylaw and Standards Changes

The City's current *Stormwater Drainage Regulation and Charges By-law, 2008, No. 16610*, makes it possible for the recommendations in ISMPs to form a part of the development criteria. The wording in this bylaw largely negates the need for bylaw changes or new bylaws. However, there are clauses in existing bylaws that may conflict with the requirements proposed in this ISMP and with the latest stormwater management methodologies. The following changes are proposed in the long term:

1) Update the *Design Criteria Manual* during the next revision to include such things as standard drawings of on-lot and roadside source controls, sizing calculations, checklists, etc. Much of the

content for such a bylaw could come from the 2012 Metro Vancouver Stormwater Source Control Design Guidelines.

2) Revise the *Design Criteria Manual* during the next revision to clarify that disconnection of roof leaders is permitted on all land uses, not only “detached residential” land use. Disconnecting roof leaders must take into consideration the downslope impacts and a hydrogeologist should be consulted in steep slope areas or where downslope seepage is a concern.

3) Revise zoning bylaws to accommodate source controls on residential lots. The current trend is for higher density on some residential parcels. Large homes, coach houses, and driveway/parking areas can increase the total imperviousness of some residential lots to 80%, leaving little room for landscaping and source controls. It is proposed that, in addition to maximum building lot coverage values, maximum total impervious lot coverage values be developed with stormwater management in mind, and incorporated into the zoning bylaw.

4) Revise zoning bylaws to incorporate wider (30m) riparian setbacks. The ISMP recommends 30m riparian setbacks for the Quibble Creek main stem which may be wider than the setbacks required under the Riparian Areas Regulation (RAR). To accommodate the extra width, zoning bylaws should designate the 30m buffer adjacent to Quibble Creek as “Riparian Protection Area”.

5) Changes are needed to the inspection procedure during development and construction currently noted in the *Building By-law, 1987, No. 9011*, to include the need for inspections of source controls, proper piping connections, overflows, etc. These changes must occur alongside training for the municipal inspectors as they may not be aware of the requirements and LID practices.

6) Explore public reception to incorporating wording into the *Property Maintenance and Unsightly Premises Bylaw, 2007, No. 16393*, to clarify that boulevard maintenance activities required under the bylaw include the maintenance of source controls such as rain garden weeding, watering, debris removal, etc. within the boulevard and on lot.

Enforcement Tools

To effectively enforce the ISMP vision, goals, criteria, and plan, the following tools are recommended:

- **Bylaws** – revise bylaws as noted above and enforce current bylaws. Minimize the granting of development variances that seek to reduce or eliminate BMPs.
- **Permits** – continue checking plans submitted by developers for conformance with bylaws and ISMP requirements. Utilize source control design/sizing checks (see Checklists section below).
- **Inspections** – confirm that approved designs are being implemented during construction. Check stormwater facilities, riparian setbacks, sediment and erosion control, etc. City inspectors may require training to inspect stormwater BMPs.
- **Maintenance** – Perform annual inspections of stormwater BMPs for commercial/industrial properties. Alternatively, require owner/tenant to obtain independent annual inspection by a professional to be submitted with business license renewal.
- **Monitoring** – Collect water quality and flow data on an ongoing basis to confirm that the minimum ISMP goal of no-net-loss is being achieved. Follow Metro Vancouver Adaptive Management Framework process (see Section 7.10 for additional information).

Checklists for Design and Maintenance

Checklists for ensuring that source controls are sized to meet the ISMP criteria that can be used by the Planning and Development Department during building permit and development permit applications have been developed and are included in Appendix I. There is a generic checklist and also source control specific checklists included.

A maintenance checklist to be used during and after construction is also included in Appendix I. In addition to this checklist, the following maintenance activities are recommended.

Inspection: The Quibble Creek drainage systems should be inspected every 5 years during low flow conditions, ideally in the winter so that remediation of identified problems can be undertaken during the following summer dry months. The primary purpose of the inspection is to assess the condition of the conveyance facilities including creek channels for erosion locations and hydraulic structures, and identify the need for maintenance. The inspection should include all open channels, culverts, ponds, diversions, flow splitters, and floodboxes. An overall drainage system inspection should also be completed after large storm events.

Vegetation Maintenance: Access to ditches and the conveyance ditches themselves should be maintained to prevent the growth of weeds, small trees and bushes. The hydraulic conveyance capacities of the ditches must be maintained. Ditch maintenance should occur annually.

Sediment Removal: Sand/silt accumulation in sumps and catch basins is expected and should be removed every two years, ideally at the end of summer before the autumn rainy season.

Debris Control: Debris blockages at hydraulic structures can cause flooding problems. Annual inspection and regular debris removal (as required) from the ditches, culverts and floodboxes is necessary.

Wet Ponds: Inspect periodically during wet weather to observe function, clean sediment forebay every 5 to 7 years or when 50% capacity has been lost, remove accumulated sediment form pond bottom when 10 to 15% of pool volume is lost, inspect hydraulic and structural facilities annually and mow side-slopes, embankments and spillways as required to prevent excessive over growth that may reduce the flow capacity.

Detention Tanks: Inspect annually and remove floating debris and oil.

Wetlands: Inspect annually and after each major storm event. At beginning of wet season remove trash and floatables and unclog outlet structures.

Grassed Swales: Inspect routinely especially after large storm events. Correct erosion problems as necessary, mow to keep grass in the active growth phase, remove clippings to prevent clogging of outlets, and remove trash and debris.

Bioretention with Underdrain: Remove leaves each autumn, inspect overflow, hydraulic and structural facilities annually.

Education Strategy

The City of Surrey already engages in several educational programs that increase public awareness of environmental and habitat issues. The Salmon Habitat Restoration Program (SHaRP) and Surrey Natural Areas Partnership (SNAP) both employ post-secondary and high school students to continue habitat restoration, natural area preservation, water quality assessment, environmental education and outreach in the City. The programs are an excellent venue to educate business and community members about the possible negative environmental effects of stormwater and why integrated stormwater management is so important. a program that. The City should also continue to work with schools to encourage student involvement in stream clean-up, riparian planting, and other activities.

There are several other initiatives that the City of Surrey can start to educate the public and businesses on the importance of integrated stormwater management. These include:

- Continuing to hold workshops and forums like the recent "Livable City Architecture Thorough Greenscaping" workshop held in September 2013 that engaged designers, architects and other professionals;
- Holding internal workshops to educate City Staff, coordinating with upcoming Metro Vancouver workshops if timing allows;
- Holding workshops for builders and developers (this is currently underway);
- Creating a brochure to be handed out with building permits and development permit applications to explain the on-lot requirements for development in the watershed; and
- Setting up small booths at every public open house or other such event to help raise awareness about stormwater and environmental issues with the public. Generally the public is aware that stormwater can be damaging to a watershed, but are unaware of what they can do to help.

Further outreach could be achieved by creating a newsletter about restoration, environmental outreach or other management activities happening within the Quibble Creek watershed. This document could be posted on the City web-site or mailed to residents and businesses. The newsletter could highlight exemplary stormwater or environmental projects that are happening within the watershed and could provide simple examples of measures that could be done by individual home owners or businesses to improve the stormwater quality or reduce the runoff volume leaving their properties. This could include items such as rain-barrels for water re-use, absorbent landscaping to reduce the quantity of runoff, and treatment options to improve water quality.

7.10 Monitoring Strategy and Adaptive Management

Monitoring Framework

Metro Vancouver has produced a draft Adaptive Management Framework (AMF) which provides guidance on stormwater monitoring, assessing the effectiveness of ISMPs and recommending adaptive management practices. It is recommended that the City adopt the AMF as a guide to monitor watershed health and assessing ISMP effectiveness in Quibble Creek. The AMF is intended to be a 'living document' where the framework will be updated every five years or as required

Based on the AMF, Quibble Creek is classified as a higher gradient stream (average channel slope >1%). Water quality, hydrometric, and benthic invertebrate monitoring is recommended for this stream type with a recommended frequency of no more than every five years.

A core set of water quality parameters and their priority (priority or secondary parameter classification) for measurement in higher gradient streams are listed in Table 7-10 below. Some of these parameters were measured during the ISMP as noted in the table.

The implementation of the ISMP recommendations is intended to have the effect of improving the water quality toward meeting the British Columbia Water Quality Guidelines (primary contact and protection of fish and aquatic life).

Table 7-10: Priority (P) and Secondary (S) Water Quality Indicators

Parameter	Discussion	Priority Class	Measured in ISMP	Desired Trend
General Parameters				
Dissolved Oxygen	Watercourses with flowing water, such as mountain streams, tend to contain more dissolved oxygen (DO), than low flow or still waters. Bacteria in water can consume oxygen as organic matter decays. DO in surface water is also controlled by temperature, with cold water holding more DO than warm water. This parameter is considered to be more important in lowland watercourses, particularly during the summer, where low DO levels can negatively influence resident fish.	P	Y (Mean 12.1 mg/L)	Increase
pH	Changes in pH can indicate the presence of particular effluents that may be detrimental to aquatic life, such as road runoff or a spill (e.g., the introduction of concrete wash water can significantly increase water pH).	S	Y (Mean 7.67)	Neutral pH
Water Temperature	Elevated water temperatures can affect the development of fish eggs, rearing of juvenile fish, and the movement and migration of adult salmonids. Increased water temperature is a potential indicator of loss of riparian habitat upstream (reduced shading), increase water retention (perhaps due to an increase in number and size of stormwater detention ponds).	P	Y (Mean 14.5°C)	Decrease
Conductivity	Conductivity is a broad measure of ionic concentration. Watershed geology and relative contribution of groundwater exert a strong influence on background conductivity. However more urbanized systems typically have a much higher conductivity level relative to natural forested streams with similar geology and groundwater inputs. Discharges to streams can change the conductivity depending on their make-up. A failing sewage system would raise conductivity because of the presence of chloride, phosphate, and nitrates; an oil spill would lower conductivity.	S	Y (Mean 327 μS/cm)	No increase
Turbidity	Increased turbidity could indicate that there is increased erosion upstream. Higher amounts of dissolved or suspended solids result in increasing turbidity.	P	Y (Mean 3.7 NTU)	No increase

Parameter	Discussion	Priority Class	Measured in ISMP	Desired Trend
Nutrients				
Nitrate (as Nitrogen)	High levels of nitrogen can be indicators of pollution from man-made sources, such as septic system leakage, poorly functioning wastewater treatment plants, or fertilizer runoff. Some nitrate enters water from the atmosphere, which carries nitrogen-containing compounds derived from automobiles and other sources.	P	N	<13 mg/L
Microbiological Parameters				
Escherichia Coli	The presence of E. coli can indicate contamination from human and animal waste. Animal waste typically enters watercourse via stormwater.	P	N	Decrease
Fecal Coliforms	High fecal coliform bacteria can indicate contamination with fecal material (humans or other animals). Sources can include agricultural runoff, effluent from septic systems (groundwater contamination) or sewage discharges. Bacteria (from bird and wildlife fecal material) also enter aquatic systems via stormwater. Human waste contamination can occur via combined server overflows (CSOs) or from spill events.	P	N	Decrease
Metals				
Iron	Stormwater is a significant source of a wide range of metals including iron, copper, lead, zinc, and cadmium. Sources include roof flashings and shingles, gutters and downspouts, galvanized pipes, vehicle exhaust, and tire and brake linings/rotors. High levels of iron can also be an issue in agricultural drains in parts of the Lower Mainland. The issue occurs when iron is mobilized from farm soils or from groundwater seepage (iron is oxidized).	P	N	<0.3 mg/L
Copper		P	N	<2 µg/L
Lead		P	N	<1 µg/L
Zinc		P	N	<30 µg/L
Cadmium		P	N	<0.018 µg/L
Source: *Monitoring and Adaptive Management Framework Draft Report*, Metro Vancouver (2013).				

Proposed Monitoring Program

The proposed monitoring program focuses on answering two essential questions:

1. Is development/redevelopment negatively impacting the ecological health of creeks?
2. Are stormwater management activities maintaining the overall health of the creeks?

Based on the above monitoring framework, the following monitoring is proposed in the Quibble watershed.

1. Continue collecting continuous flow monitoring data on the Quibble Creek main stem at 88 Avenue. This site has been subject to vandalism in the past. Frequent site inspections and data review are recommended to ensure that adequate flow data is collected. A review of alternate sites could be performed if vandalism cannot be managed.

2. Continue collecting B-IBI samples on the Quibble Creek main stem south of 88 Avenue as part of the City's long-term benthic monitoring program (annual monitoring). This monitoring frequency will exceed the Metro Vancouver AMF minimum requirement.
3. Collect water quality samples at the following three sites and analyze samples for all of the parameters listed in Table 7-10. Monitoring should begin in 2014 to provide a baseline for assessing the effectiveness of the ISMP. The AMF requires sampling twice during the year –in the wet season (between November and December) and in the dry season (between July and Aug). Each seasonal monitoring period will occur over a 30-day period, with samples collected five times (preferably on a weekly basis). The AMF does not specify the minimum number of sampling locations. The following three locations are recommended:
   - Site 1: Quibble Creek in Bear Creek Park (downstream of 88 Avenue)
   - Site 2: Quibble Creek downstream of 100 Avenue (upper extent of open stream)
   - Site 3: Tributary T3 :King George Creek

Adaptive Management

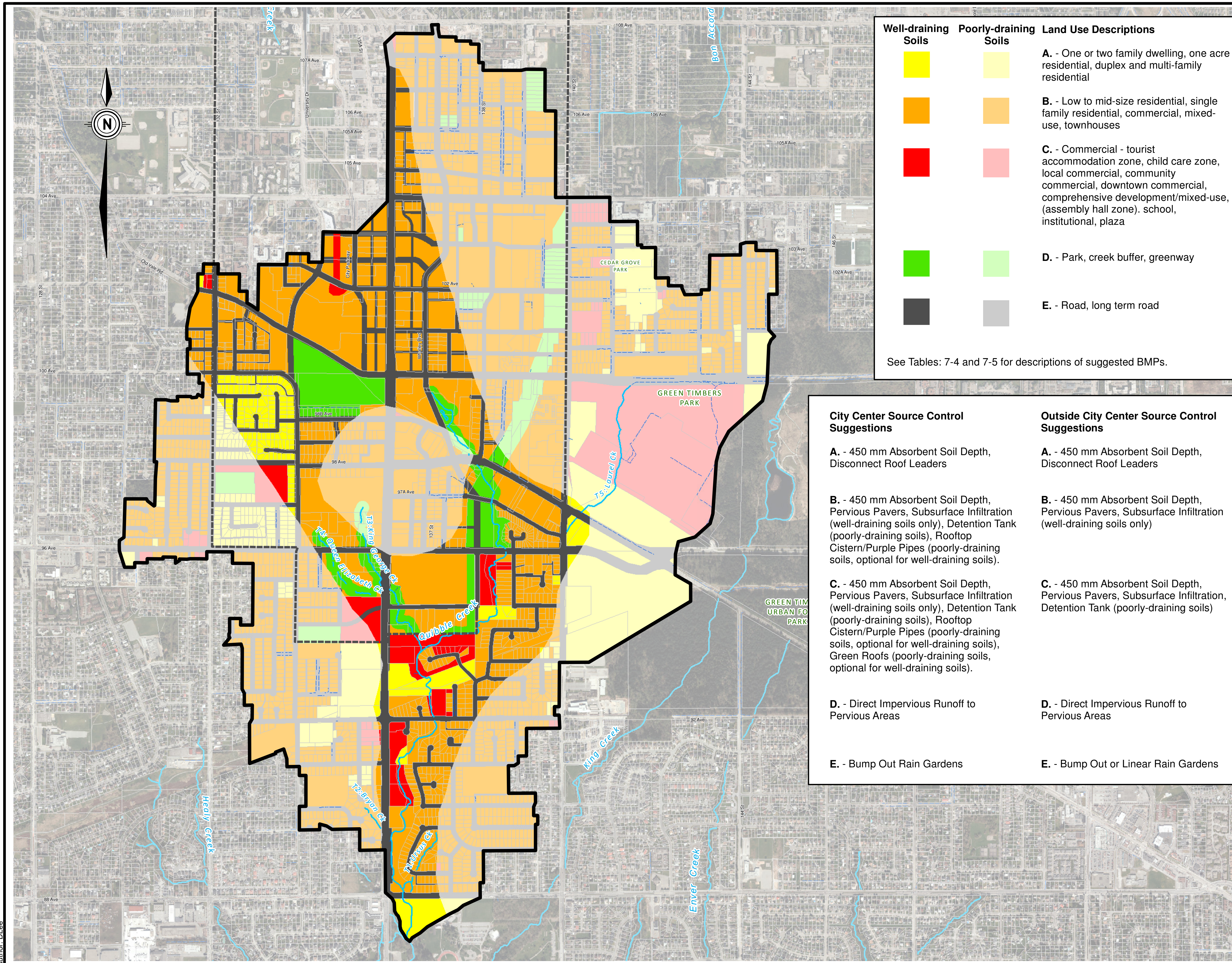
To ensure the ISMP plan is unfolding as intended, an Adaptive Management Program is recommended. Preserving the ecological health of a watershed requires a comprehensive planning process and the ability to reassess and redirect efforts as required over time. It is important to monitor the impacts of development and the performance of implemented works and programs to assess if they are effectively meeting the ISMP goals. The data must be interpreted carefully and if the results are less than satisfactory, the program must be re-examined and efforts realigned. This is particularly important with rapidly evolving stormwater management technologies.

The indicators in the proposed monitoring plan described in the above section must be tracked over the long term in order to be useful in evaluating changes in the water bodies. The indicators do not have to all move in a particular direction, up or down, in order to show maintenance or degradation in overall watershed health. Rather the tracked suite of indicators should be reviewed every cycle to:

- Note movement in particular indicators,
- Evaluate possible causes of the movement,
- Determine if the movement of the indicators represents an impact,
- Evaluate if the indicator movement is expected or unforeseen, and
- Review the goals, elements, and implementation plan of the ISMP to assess if changes should be made to the plan in order to remain on track and achieve the overall stormwater goals over the implementation timeline for the ISMP.

The schedule for a full assessment and review for the watershed health indicators should be at least once every five years. Therefore, four full reviews of the indicators should occur during a 20-year expected timeline for implementation, and tracking to assess the impacts of full implementation should be continued by the City, at least once every five years, beyond that horizon.

As recommended in the Metro Vancouver AMF, rather than preparing an adaptive management plan for each drainage system, municipalities will prepare a plan for adaptive management on a municipal wide basis. A municipal adaptive management plan will prioritize issues arising from the water quality, flow monitoring and benthic results in all systems monitored to date and then schedule measures to address the highest priority issues first. Phasing adaptive management actions will also help to keep costs manageable.



Well-draining Soils	Poorly-draining Soils	Land Use Descriptions
(yellow)	(pale yellow)	**A.** - One or two family dwelling, one acre residential, duplex and multi-family residential
(orange)	(light orange)	**B.** - Low to mid-size residential, single family residential, commercial, mixed-use, townhouses
(red)	(pink)	**C.** - Commercial - tourist accommodation zone, child care zone, local commercial, community commercial, downtown commercial, comprehensive development/mixed-use, (assembly hall zone). school, institutional, plaza
(green)	(light green)	**D.** - Park, creek buffer, greenway
(dark grey)	(light grey)	**E.** - Road, long term road

See Tables: 7-4 and 7-5 for descriptions of suggested BMPs.

City Center Source Control Suggestions	Outside City Center Source Control Suggestions
A. - 450 mm Absorbent Soil Depth, Disconnect Roof Leaders	**A.** - 450 mm Absorbent Soil Depth, Disconnect Roof Leaders
B. - 450 mm Absorbent Soil Depth, Pervious Pavers, Subsurface Infiltration (well-draining soils only), Detention Tank (poorly-draining soils), Rooftop Cistern/Purple Pipes (poorly-draining soils, optional for well-draining soils).	**B.** - 450 mm Absorbent Soil Depth, Pervious Pavers, Subsurface Infiltration (well-draining soils only)
C. - 450 mm Absorbent Soil Depth, Pervious Pavers, Subsurface Infiltration (well-draining soils only), Detention Tank (poorly-draining soils), Rooftop Cistern/Purple Pipes (poorly-draining soils, optional for well-draining soils), Green Roofs (poorly-draining soils, optional for well-draining soils).	**C.** - 450 mm Absorbent Soil Depth, Pervious Pavers, Subsurface Infiltration, Detention Tank (poorly-draining soils)
D. - Direct Impervious Runoff to Pervious Areas	**D.** - Direct Impervious Runoff to Pervious Areas
E. - Bump Out Rain Gardens	**E.** - Bump Out or Linear Rain Gardens

City of Surrey
Quibble Creek
Integrated Stormwater Management Plan

Legend

- Study Area
- City Centre Boundary
- Ditch
- Watercourse

Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.

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Project No.	Date
471-239	February 2014

Suggested BMPs by Land Use and Soil Type

Figure 7-1

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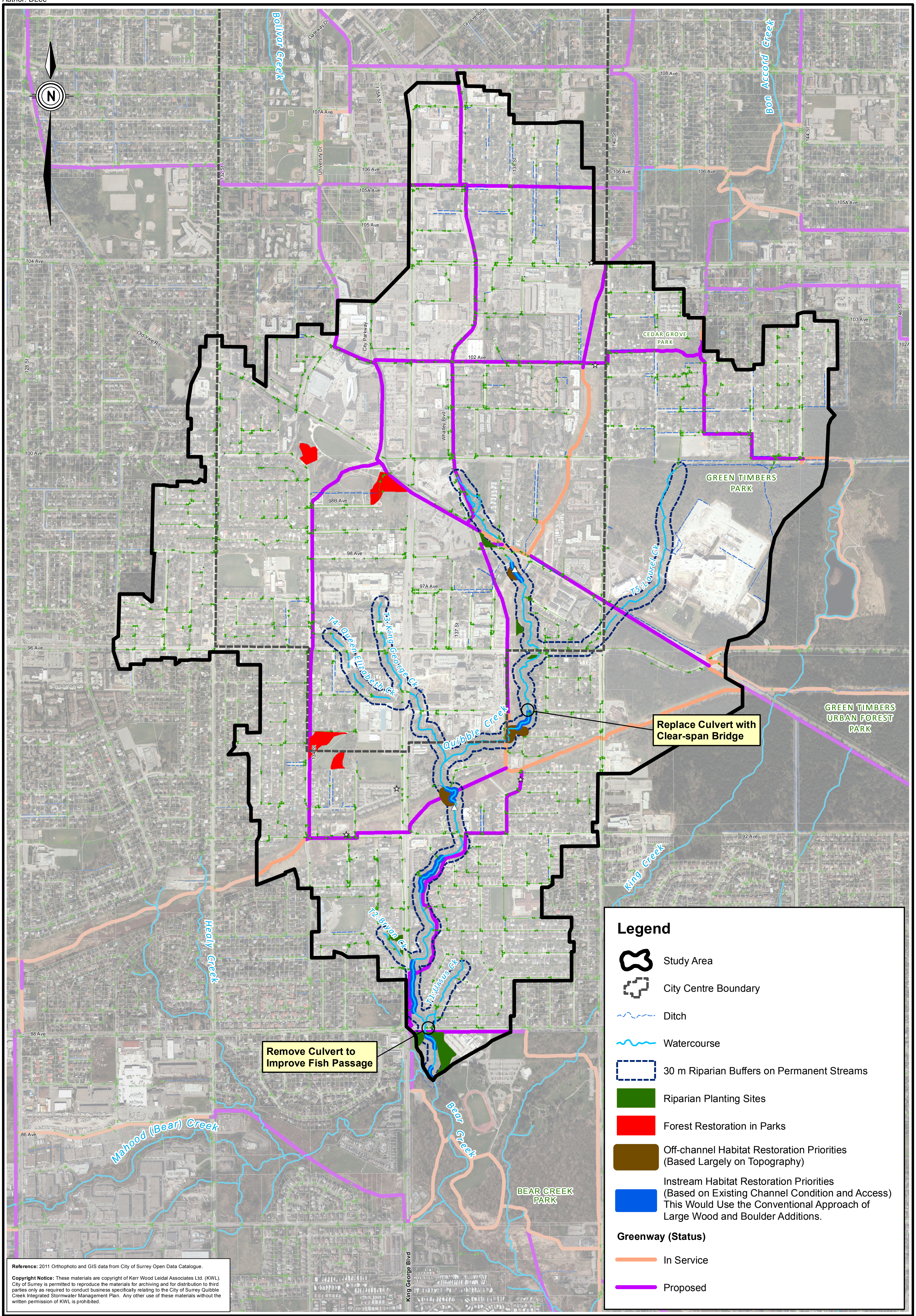

Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.

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City of Surrey
Quibble Creek Integrated Stormwater Management Plan

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Environmental Compensation and Enhancement Works

Figure 7-2

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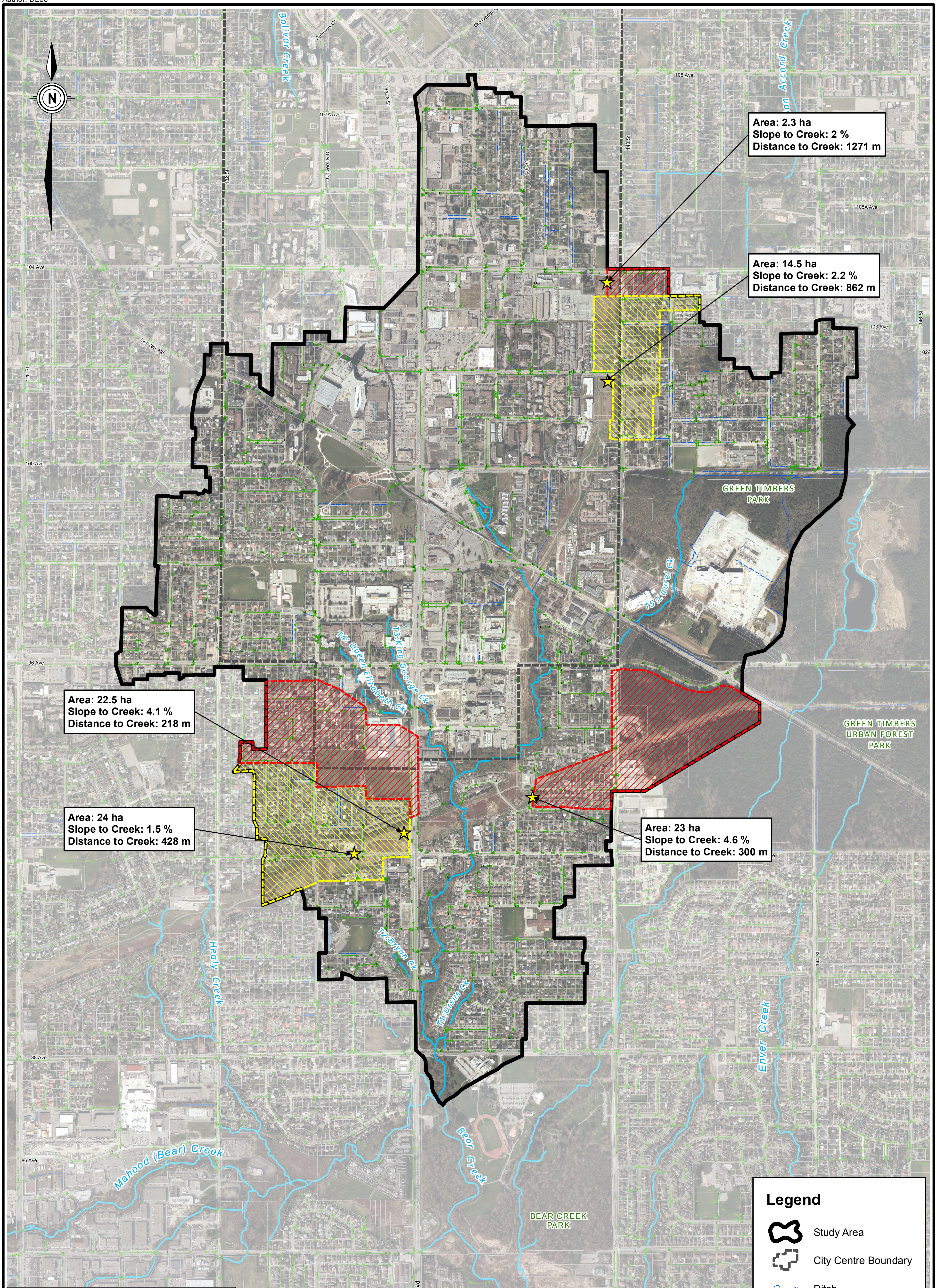

Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.

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Potential Regional Water Quality Facilities

Figure 7-3

Section 8

Summary and Recommendations

8. Summary and Recommendations

8.1 Summary

Introduction

- The Quibble Creek ISMP employed a multi-disciplinary approach including stormwater engineering, and environmental protection.
- Key ISMP objectives included identifying habitat enhancement opportunities, determining how to allow development with minimal effects on flooding, erosion, water quality and ecological health, providing long-term "Net Gain" in the watershed, and meeting the LWMP stormwater commitments.
- Applicable stormwater criteria included Surrey 5-year minor and 100-year major conveyance standards and detention criteria.

Quibble Creek Watershed

Land Use

- The existing and future land uses were summarized. The existing land use is highly developed with a percent impervious of 67%. The future land uses increased the density of development with a percent impervious of 74%.
- Previous reports indicated a high level of roof leader disconnection in the residential areas (approximately 80%). Disconnected roof leaders contribute to decreased connectivity in the developed impervious area to the creek.

Drainage Inventory

- The Quibble Creek watershed is 656 ha, including 335 ha in the City Centre core (51% of the watershed), and drains south to Bear Creek. Bear Creek is a major tributary of the Serpentine River which discharges to the Pacific Ocean at the Mud Bay Estuary.
- 41 erosion sites were identified and ranked (30 low risk sites, 9 medium risk sites and 2 high risk sites) and 14 obstruction sites were identified during the field inventory
- A drainage inventory included investigations on creek crossings, erosion, deposition, obstructions, and a condition assessment of hydraulic structures and outfalls.

Environmental Inventory and Assessment

- Quibble Creek is remarkable because of good quality instream and riparian habitat despite the high level of watershed urbanization. It is also important as an accessible fish-bearing stream in proximity to Surrey's developing City Centre.
- Good quality instream habitat supports spawning and rearing habitat for wild coho salmon, chum salmon, and cutthroat trout. In November 2012, 122 adult coho and 537 adult chum were observed spawning in Quibble Creek, mainly in the mainstem.
- The water quality survey found conditions typical of urbanized streams in Metro Vancouver. The survey did not find any specific sites or stream sections with elevated or unusual water quality characteristics which would indicate specific sources of contamination (e.g., "hot spots").

- Metals in sediment (an indicator of urbanization) were generally lower than other urban streams in Metro Vancouver. This result was unexpected given the level of urbanization in the Quibble Creek watershed.
- B-IBI (Benthic Index of Biotic Integrity) was used to summarize benthic invertebrate (streambed insect) data. Mean B-IBI was 14.1 which is consistent with the high level of urbanization in the Quibble Creek watershed.
- A total of 87 ha (13%) of the Quibble Creek watershed was forested in 2011. Approximately 20 ha (3%) of watershed forest cover has been lost since 1995. Approximately 22 ha (60%) of the Quibble Creek riparian zone is currently forested, mainly with deciduous forest. Riparian forest cover has remained stable over the past 16 years largely because of regulation of development in riparian areas.
- Fish passage improvements could improve access to tributary streams for migratory fish such as coho salmon.

Modelling and Engineering Assessments

Hydrologic and Hydraulic Modelling

- A PC-SWMM model was created for the Quibble Creek catchment and drainage system for both the existing, and future (unmitigated) land use conditions. The existing model was calibrated and validated.
- During calibration the impervious coverage for the existing land use scenario was adjusted to reflect the EIA for the watershed use to the high level of hydrologic disconnection in the watershed. The future conditions EIA was estimated based on engineering judgement.
- The design storms used were those contained in the City of Surrey *Design Criteria Manual* (2004). The 2-, 5-, 10-, and 100-year return period 1-, 2-, 6-, 12-, and 24-hour
- Continuous simulation modelling was performed using rainfall from 1985 to1998 from the Kwantlan Park rain gauge. Results were used to produce exceedance duration curves. The models were run for three scenarios: existing land use conditions, future unmitigated land use conditions, and future mitigated land use conditions. Results show that overall the future conditions have more hours at any given flow that the exiting conditions and that the mitigated curve matches the existing curve for lower, more frequent flows, then slowly decreases to below the existing curve for the higher, less frequent flows.
- Peak flows for design events were estimated at 88th Avenue (at flow monitoring gauge location).
- The future land use, if left unmitigated, would increase the 2-year to 100-year peak flows by approximately 15% to 63%.
- A system capacity assessment was performed on the 1,424 conduits in the model. The minor system was checked using the 5-year peak flow limiting the surcharge time to 15 minutes and surcharge height to 0.3 m. 19 pipes fail the minor system capacity check under existing land use conditions and additional 122 pipes fail the minor system capacity check under future unmitigated land use conditions.
- The major system was checked using the 100-year peak flow limiting the surcharge to below the ground (flooding not allowed). Four pipes fail the major system capacity check under existing land

use conditions and an additional three pipes fail the major system capacity check under future unmitigated land use conditions.

Vision for Future Development

- A key part of the ISMP process is to establish the vision, goals, and criteria for the watershed.
- A visioning workshop and architect meeting were held to consult with stakeholders to determine these values.

Visioning Workshop

- The City visioning workshop developed three pillars with goals for each pillar to allow the vision to be achieved.
- Pillar 1: Quibble Creek is to remain an essential part of the developing City Centre, providing access to nature, educational opportunities, and significant habitat. The goals to achieve this include protecting and enhancing riparian area and salmon habitat, enhancing and increasing the connectivity of green infrastructure, reconnecting disconnected tributaries, improving recreational access to the creek, and involving developers and residents in project planning, implementation, and monitoring to promote awareness.
- Pillar 2: Protecting and maintaining, or improving the long-term net health of the watershed through the building and re-development process. The goals to achieve this include incorporating source controls into the design of neighbourhoods, roads, and buildings; and promoting and incorporating on-site rainwater management into all developments to the maximum practical extent
- Pillar 3: Continuing to protect life and property from erosion and flooding with stormwater infrastructure. The goals to achieve this include upgrading failing or undersized stormwater infrastructure and preventing flooding due to increased peak flows form developed impervious area, and providing adequate detention on site to maintain post-development flows at pre-development levels

Architects Meeting

- The goal of the architects meeting was to enhance the implementation of the ISMP by involving the architects in the process of selection of Low Impact Development techniques and site level BMPs that will be recommended by the ISMP.
- One of the key ideas from the architects meeting was that in order for het ISMP recommendations to get implemented, residents, developers and other professionals that live and/or work in the watershed need to be aware of Quibble Creek and that this could be achieved by showcasing the creek as an important asset in the City Centre that provides access to nature.
- Developers were generally open to the idea of BMPs, but cost and space requirements are barriers to wide spread use.
- Several tools and strategies were identified to allow for successful implementation of BMPs.

Integrated Stormwater Management Plan

- Stormwater criteria are proposed for volume and rate control for watershed outside of City Centre area; capture target of 32 mm of rainfall (50% of 2-year 24-hour) and for rate control, release 5-year post-development flow to 50% of 2-year post-development flow or 5-year post-development flow to 5-year pre-development flow rate.

- For the City Centre area the criteria is taken from *Surrey City Centre General Land Use Plan Update – Utility Servicing* (AECOM 2010) report; the volume capture target is also 32 mm of rainfall, and for rate control to reduce post-development flows to pre-development flows, for the 2, 5 and 10-year 24 hour storm.
- The key issues in the watershed include: flood management, erosion management, mitigation of future development/redevelopment impacts, and environmental protection and enhancement.
- A capital upgrade plan was developed to address the conveyance capacity issues. The costs are as follows:
  - Priority 1: Major system, existing 100-year analysis, flooding $1,920,000;
  - Priority 2: Minor system, existing 5-year analysis, flooding, $52,100;
  - Priority 3: Minor system, existing 5-year analysis, surcharge, $218,000;
  - Priority 4: Major system, future 100-year analysis, $208,500;
  - Priority 5: Minor system, future 5-year analysis, two incremental dia. or more, $875,000;
  - Priority 6: Minor system, future 5-year analysis, one incremental dia, $1,675,000.
- Two high risk erosion sites have been identified for urgent attention by the City that require bank stabilization or repair. Further assessment of identified sites should be completed by a geotechnical engineer prior to mitigation works. The remaining erosion sites are considered medium to low risk and should be monitored as part of the City's Ravine Stability Assessment.
- Water quality treatment for future development and redevelopment should primarily be accomplished by applying volume reduction source controls. Areas where the water quality is not sufficiently treated via source controls, regional water quality facilities such as oil and grit separators will be needed near outfalls leading to the creek systems.
- Six sites totalling 1.5 ha were identified for reforestation within the Quibble Creek riparian corridor. The largest site (1.1 ha) is located in Bear Creek Park. Riparian reforestation costs are estimated at approximately $120,000 per hectare. Additional sites are identified for invasive species management.
- Seven instream habitat restoration sites (stream segments) totalling 835 m of channel were identified. The density of large wood and deep pools suggest that instream habitat restoration could increase fish habitat value.
- Two sites were identified for fish passage improvements and involve either removal or replacement of existing culverts.

8.2 Recommendations

Based on the above summary, it is recommended that the City:

a) Adopt proposed stormwater criteria for Quibble Creek watershed and specific City Centre criteria and educate developers on bylaws, policies and procedures;

b) Require 450 mm of absorbent topsoil on all pervious areas and grading impervious areas to pervious areas for single family residential lots;

c) Require source controls on multi-family residential, neighbourhood attached residential, commercial, institutional and industrial development and roads;

d) Install regional water quality facilities such as oil and grit separators at outfalls for areas where water quality criteria are not met on site via source controls in upstream catchment;

e) Develop schedule to construct Priority 1 and 2 upgrades within the next ten years including storm sewer and culvert upgrades, lower priority upgrades can be upgraded at end of design life or during redevelopment;

f) Further assess identified erosion sites by a geotechnical engineer prior to completing recommended erosion mitigation works for the two high risk sites and continue monitoring the remaining erosion sites as part of the City's biannual Ravine Stability Assessment;

g) Initiate riparian and instream enhancement projects, including fish passage improvements as shown on Figure 7-2.

h) Monitor watershed health as per Adaptive Management Framework to maintain watershed health over long term.

8.3 Report Submission

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Statement of Limitations

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This document represents KWL's best professional judgement based on the information available at the time of its completion and as appropriate for the project scope of work. Services performed in developing the content of this document have been conducted in a manner consistent with that level and skill ordinarily exercised by members of the engineering profession currently practising under similar conditions. No warranty, express or implied, is made.

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Revision History

Revision #	Date	Status	Revision	Author
3	February 17, 2014	Final	Address City comments and finalize report	DGSL, DZ
2	December 9, 2013	Draft	Draft of Final Report	DGSL, DZ
1	June 14, 2013	Draft	Up to Stage 3	AH, SP, DGSL
0	November 15, 2012	Draft	Stage 1 Report Sections	AH, SP, LM

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Appendix A

Watershed Overview

Appendix A – Watershed Overview

Contents

Figures

Tables

Appendix A – Watershed Overview

A Watershed Overview

A.1 Understanding Stormwater Management

Introduction

This section outlines stormwater impacts associated with land development. Impacts caused by both large, infrequent storm events and small, frequent storm events are discussed, and the primary factors affecting stream health are also reviewed.

Understanding the Impacts of Land Development

Land development typically involves replacing pervious forested area with agricultural land followed with impervious pavement, concrete and building structures. Redevelopment typically involves replacing developed areas with higher density land use with a further increase in total impervious area (TIA). Increasing impervious area results in two types of impacts:

- **Stormwater Quantity Impacts:** Increased and faster responding peak flow rates during extreme rainfall-runoff events can cause flooding and erosion, and during typical rainfall events can trigger watercourse instability and deteriorate aquatic habitat. Baseflows during dry weather periods decrease and therefore reduce the fish support capacity of a watercourse.
- **Stormwater Quality Impacts:** Land development and building construction activities result in sedimentation of watercourses. It has been found that urbanization over 30% TIA also results in non-point source (NPS) pollution of receiving waters and poor stream water quality. Together, sediment and contaminants can significantly degrade the fisheries value of a creek system.

Stormwater Quantity Impacts

Stormwater quantity impacts can be segregated into two types, those associated with large infrequent storm/runoff events and those associated with smaller, more frequent ones, as follows:

Table A-1: Stormwater Quantity Impacts of Land Development

Storms	Return Period Event	Resulting Runoff	Potential Impacts of Development	Type of Assessment
Infrequently Occurring Large Storms	10-year to 100-year	Runoff results from both impervious and pervious areas for both the undeveloped and urbanized conditions, but a quicker, greater response occurs under the urbanized condition.	Flood and erosion damage	Hydrotechnical
Frequently Occurring Small Storms	Less than 2-year	Very little, if any, runoff is generated under natural forested conditions. Once land is urbanized, however, runoff results.	Stream corridor 'wear-and-tear' & deterioration of aquatic habitat	Environmental

Appendix A – Watershed Overview

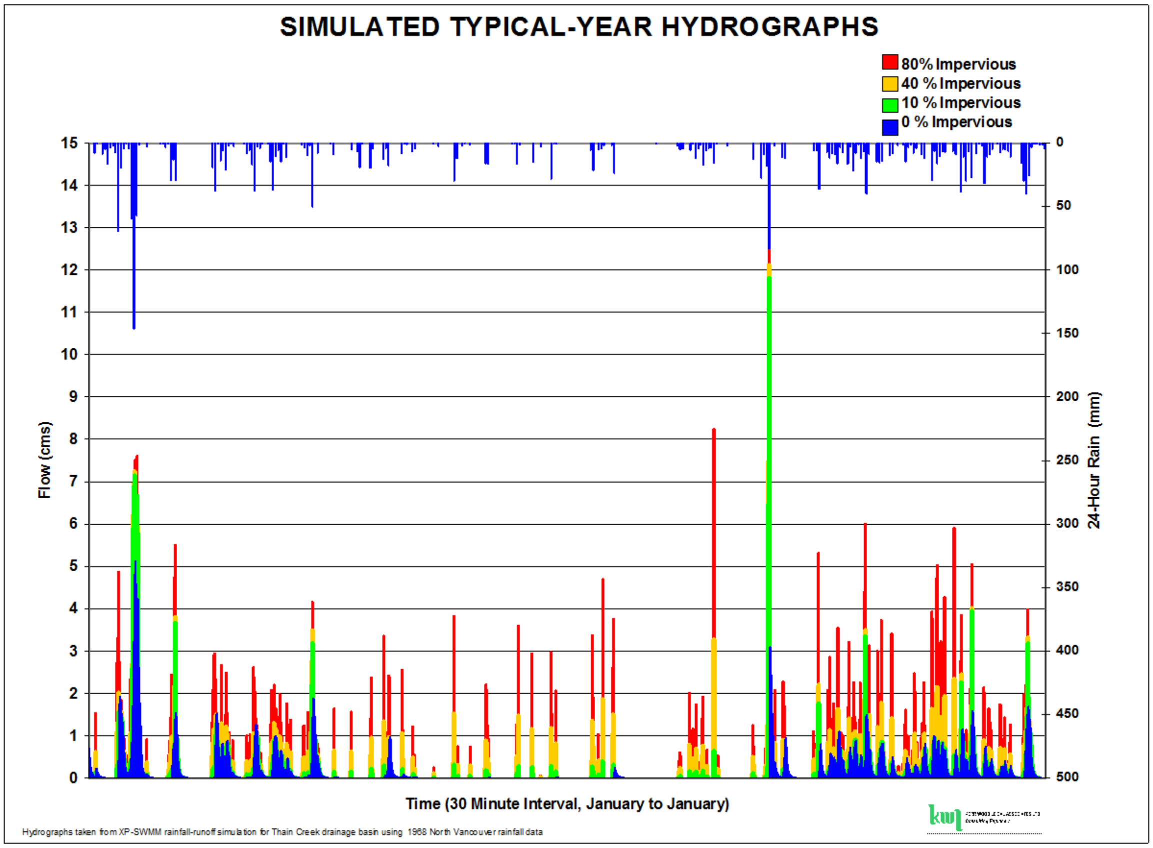

Figure A-1: Simulated Typical-Event Hydrograph for Levels of Imperviousness

Prior to land development, minor rainfall events do not yield surface runoff. However, because of increased impermeable area, surface runoff from these minor storms is produced after land development. This is clearly shown in the typical-year hydrograph for various levels of development (refer to following figure).

Research has shown that urban development, which typically increases impervious area and decreases riparian corridor, significantly impacts the abundance and diversity of fish populations and benthic macroinvertebrate communities. This is illustrated conceptually in Figure A-3.

The increased frequency of higher runoff rates and volumes causes watercourse wear and tear. The Mean Annual Flood (MAF) is a key parameter because watercourses tend to be in equilibrium under the MAF. The consequence of increasing the MAF is channel erosion until the channel widens or deepens to the point of establishing a new equilibrium. Erosion and sedimentation processes then progressively eliminate aquatic and riparian habitat.

STORMWATER IMPACTS OF INCREASING URBANIZATION

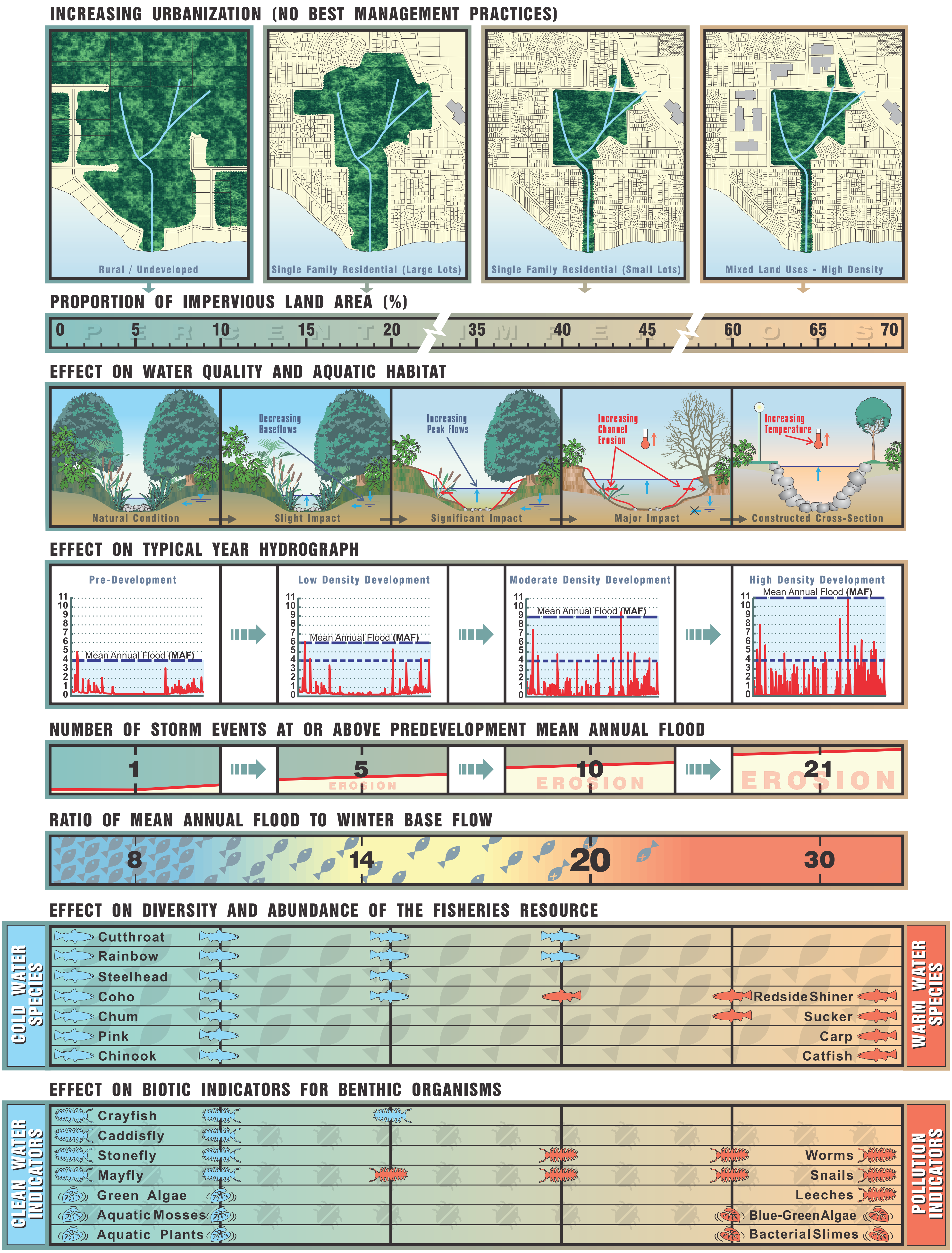

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Figure A-2

Appendix A – Watershed Overview

The reduction in groundwater infiltration and recharge results in lower baseflows, and hence higher ratios of peak flows to baseflows.

Primary Factors Limiting the Ecological Health of Urban Waterways

Recent research on urban streams indicates that four primary factors affect its ecological health. They are listed, in order of importance, as follows:

- changes in hydrology;
- disturbance to the riparian corridor;
- disturbances to fish habitat; and
- deterioration in water quality.

'Changes in hydrology' can be viewed as the paramount factor because it can impact the other factors. Increases in hydrology (flows and volumes and the frequency of their occurrence) accelerates natural rates of erosion and sedimentation, degrades or washes out aquatic and riparian habitat, and deteriorates water quality.

By the time pollutant loading is a significant water quality problem affecting fish survivability, the higher frequency of occurrence of increased flows resulting from land use densification have already degraded or disturbed the physical features associated with productive fish habitat.

Understanding the four limiting factors is key to developing guiding principles for an integrated approach to the environmental component of the ISMP. Address 'changes in hydrology' on a watershed basis, and there will be spin-off benefits in mitigating the other three factors.

Ecological Health Indicator/Performance Measure - Benthic Communities

During the past decade, environmental factors have become integral to stormwater management planning. It is now widely accepted that conventional stormwater management practices are ineffective in protecting aquatic habitat. Numerous problems include everything from the way cities are built, to the type of stormwater facilities built, and to the stormwater criteria used. Even today, many Best Management Practices (BMPs) and Low Impact Development (LID) methods are unproven, and the science behind them continues to evolve. LIDs methods encourage infiltration, evaporation, transpiration, and storage of rainfall on-site to minimize runoff. These methods are gaining popularity as a tool to help minimize the negative effects of stormwater. A measure, independent of the technology, methods, and criteria, is needed to determine whether the proposed stormwater management activities are achieving their objectives. The measure should also be reproducible in order to be defensible.

The biological integrity in a watershed can be measured in the form of the benthic macro-invertebrates community or streambed insects. Benthic macro-invertebrates occupy all watercourses, and their presence is independent of barriers and blockages, commercial and sport fishing quotas, and ocean survival of salmonids.

Appendix A – Watershed Overview

The Benthic Index of Biotic Integrity (B-IBI), developed by Karr (1996-1999), is a statistical rating system to measure benthic macro-inverterbrate communities. The index reflects Pacific Northwest conditions and has proven to be reproducible across most creek systems. More information on the index and how to use it can be found at http://www.salmonweb.org/salmonweb/ and within the report *Environmental Effects of Stormwater Discharges on Small Streams - Habitat and Benthic Assessment*, April 2000 available from the GVRD.

The index ranges from a score of 10, whichindicates the watershed health is in a“poor” condition, to a score of 50indicatingthe watershed health is “excellent”. Wild salmon are expected to be found in watersheds with high scores; while fewer fish species and lower salmonid densities are expected in watershed with scores below 25.

Land use changes, BMPs, and LID standards can be linked to the B-IBI scores or number and diversity of macroinvertebrates in a creek system. The index can also be used as a predictive planning tool.

Linking B-IBI Scores with a Watershed’s Total Impervious Area

‘Changes in hydrology’ is directly linked to the concept of ‘total’ versus ‘effective’ impervious area.

- **Total Impervious Area (TIA):** Paved surfaces, building roofs and areas sealed from the underlying soils that are directly and indirectly connected to the local piped drainage system.
- **Effective Impervious Area (EIA):** Paved surfaces, building roofs and areas sealed from the underlying soils that are directly connected to the local piped drainage system. Thus, any part of the TIA that drains onto pervious ground is excluded from the measurement of EIA.

TIA is a physical measurement of impermeable surfaces typically taken from air photos, while EIA is determined through flow monitoring, and the hydrologic model calibration and verification process.

Figure A-3 is a graph showing a strong relationship between B-IBI scores and TIA. As TIA increases (watershed becomes more developed), B-IBI decreases (fewer and less diverse macroinvertebrate communities and therefore decreasing watershed health). Reducing TIA by applying the EIA concept based on the premise that impervious surfaces can be disconnected from the piped drainage system and the creek for frequently occurring events can have great environmental benefit. Implementing LIDs/BMPs that reduce EIA through the use of infiltration, attenuation, evaporation, and transpiration will reduce TIA, and increase the health of the watershed (and its B-IBI score).

Appendix A – Watershed Overview

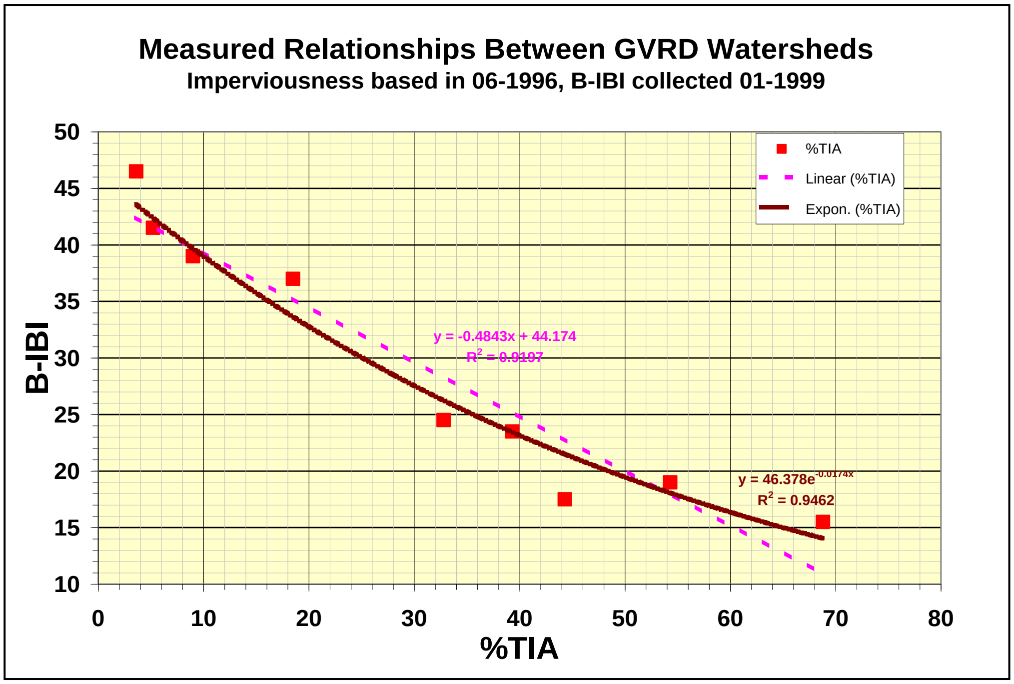

Figure A-3: Relationship between B-IBI Score and TIA

Summary of Findings

The key findings of this section are summarized as follows:

- Land development affects stormwater quantity and quality. With a TIA greater than 30%, increased peak flows and volumes for extreme events can cause flooding and erosion, and frequently occurring events can cause watercourse wear and tear resulting in erosion and deterioration of aquatic habitat. In addition, stream water quality is typically poor when the TIA is greater than 30%;
- The four primary factors affecting the ecological health of urban watercourses are, in order of importance: changes in hydrology, disturbances to riparian corridor, disturbances to fish habitat, and deterioration of water quality; and
- Benthic macroinvertebrate measurement is a biological indicator and performance measure of creek ecological health. It can be correlated with TIA and EIA.

Appendix A – Watershed Overview

A.2 City of Surrey Drainage Criteria

The *City of Surrey, Design Criteria Manual, 2004* outlines the following guiding drainage criteria:

Drainage System

- A minor system conveyance capacity up to the 1:5-year return period storm
- A major system conveyance capacity up to the 1:100-year return period storm
- Where erosion is a concern, to the more stringent of the two following criteria:
  - control the 5-year post-development flow to 50% of the 2-year post development rate; *or*
  - control the 5-year post-development flow to 5-year pre-development flow rate.

Culverts

- The minimum culvert diameter shall be 300 mm for driveways and 600mm for roadway crossings.
- Driveway culverts shall be designed to accommodate the minor flow unless otherwise indicated.

Ditches

No new ditches shall be created for servicing land development projects on Municipal rights-of-way, except in designated lowland areas where poor soil exists.

Swales

Swales shall be used in storm sewered City road allowances where there is no curb and gutter to direct the minor flow towards catch basins or the City storm sewer system. Swales shall be used in conjunction with proper lot grading to convey lot runoff, as well as to convey minor flows, and to direct major flows within rights-of-way.

Minimum Basement Elevation (MBE)
All habitable areas of buildings including crawl spaces and basements shall be above the 100-year storm hydraulic grade line (HGL), except where specific flood proofing measures to eliminate backwater effects from the downstream HGL have been taken.

Appendix A – Watershed Overview

A.3 Background Information

The available background reports are summarized in the following table.

Table A-2: Background Reports

Date	Report Title/Author
2012	10 Year Servicing Plan, City of Surrey
2011	Surrey City Centre Plan Update – Stage 2 - Status Report
2011	Zoning By-Law 12000, City of Surrey
2011	Ravine Stability Assessment, Web Engineering
2010	Surrey City Centre, General Land Use Plan Update, AECOM
2009	Ravine Stability Assessment, Web Engineering
2008	Sustainability Charter, City of Surrey
2008	Bear Creek Trunk Stability Review, Associated Engineering
2006	Fergus Creek ISMP,
2005	Ravine Stability Assessment, Associated Engineering
2004	Design Criteria Manual, City of Surrey
2002	Bear Creek Functional/Feasibility Plan, EarthTech
2002	Ravine Stability Assessment, Urban Systems
2001	Quibble Creek Functional/Feasibility Plan, EarthTech
1998	Bear Creek Master Drainage Plan, Kerr Wood Leidal
1978	Design Manual, Mater Drainage Program, City of Surrey
-	Official Community Plan, City of Surrey
-	Stormwater Drainage Regulations, City of Surrey
-	Sediment and Erosion Control Bylaw, City of Surrey

A.4 GIS Layers of Existing Drainage System

The City keeps GIS databases (layers) for a wide variety of data; GIS layers for the drainage system were provided by the City. This included streams (channels), ditches, culverts, storm sewers, and storm manholes.

The cross sections for Quibble Creek and its tributaries were created from the LIDAR data provided by the city.

The City utilized several sources of culvert information. A GIS culvert layer contained the locations, inverts, sizes, and materials for some culverts. The layer did not contain all the culverts and was

Appendix A – Watershed Overview

missing material, size and invert information. A field inspection was carried out to confirm the missing information for the major culverts.

The storm drainage system consists of storm sewers, storm manholes and detention systems. The storm sewer GIS layer contained the length, size, material, inverts, upstream manhole name, and downstream manhole name. The layer was missing some sizes and materials, as well as both upstream and downstream elevations. This missing information was assumed by interpolating between known upstream and downstream inverts and pipe sizes.

The manhole GIS Layer contained the rim elevations used for ground elevations in the model. The missing rim elevations were interpreted based on the digital elevation model (DEM).

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Appendix B

Detailed Drainage Inventory Sheets

Appendix B – Engineering Field Inventory

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B Engineering Field Inventory

B.1 Engineering Field Inventory

KWL undertook drainage inventory survey activities in May of 2012. The scope of work covered Quibble Creek and its three main tributaries.

The purpose of the survey was to supplement the City of Surrey's existing geographic information system (GIS) database by locating, photographing and assessing the following features along each major tributary:

- hydraulic structures and stormwater outfalls;
- significant bank or channel erosion sites; and
- channel obstructions.

The terms left and right in this report refer to the left and right side of the creek channel when looking downstream.

Equipment

Features and observations were positioned and recorded using a Trimble ProXT mapping grade GPS receiver together with a Trimble TSCE data collector operating Trimble Terrasync Professional field software.

All inventory features were photographed at 1600 x 1200 pixel resolution using a digital camera. Photographs were cross referenced to the GPS position and other observations within the field data collection software.

Coordinate System

The coordinate system used for this survey is Universal Transverse Mercator (UTM) Zone 10 North, North American Datum of 1983. Raw GPS positions were differentially corrected against reference data measured at base stations in Chilliwack, Vancouver, and Bellingham. Final corrected GPS positions, field observations, and photo numbers for each inventory feature were exported in ESRI shape file format, using Trimble GPS Pathfinder Office software.

Data Structure

The photographs and GPS positions associated with each feature were combined with additional field observations and measurements to produce a fully cross referenced database. The data collection structure used for this project is summarized below:

Culvert Inlet

Diameter	(mm)
Material	(CMP, concrete, PVC, etc.)
Condition	(good, fair, damaged)

Appendix B – Engineering Field Inventory

Headwall	(type)
Headwall Condition	(good, fair, damaged)
Barrier/Trash rack	(yes/no)
Overflow Height	(from invert of culvert up to road surface)
Sediment Depth	(from invert of culvert up to creek bed)
Comment	(additional notes or comments)
Photo Numbers	

Culvert Outlet and Storm Water Outfall

Diameter	(mm)
Material	(CMP, concrete, PVC, etc.)
Condition	(good, fair, damaged)
Headwall	(type)
Headwall Condition	(good, fair, damaged)
Energy Dissipation	(type)
Outlet Drop	(from invert of culvert down to creek bed)
Sediment Depth	(from invert of culvert up to creek bed)
Comment	(additional notes or comments)
Photo Numbers	

Bridge

Length	(along direction of flow)
Span	(across channel)
Height	(from creek bed up to bottom chord of bridge)
Thickness	(from bottom chord of bridge up to deck)
Comment 1	(additional notes or comments)
Comment 2	(additional notes or comments)
Photo Numbers	

Erosion

Location	(left bank, mid-channel, right bank))
Severity	(low, moderate, high)
Consequence	(low, moderate, high)
Length	(along direction of flow)
Depth	(height of eroding bank, or depth of eroded channel)
Comment	(additional notes or comments)
Photo Numbers	

Deposition

Location	(left bank, mid-channel, right bank)
Length	(along direction of flow)
Width	(across channel)
Comment	(additional notes or comments)
Photo Numbers	

Bank Protection

Type	(riprap, wall, gabions, etc.)
Location	(left bank, mid-channel, right bank)

Appendix B – Engineering Field Inventory

Length	(along direction of flow)
Height	(vertically from creek bed to top of bank protection)
Comment	(additional notes or comments)
Photo Numbers	

Channel Obstruction

Cause	(natural, anthropogenic)
Stability	(unstable, stable, fixed)
Type	(logjam, beaver dam, concrete weir, etc.)
Drop	(change in creek bed elevation from upstrm. to dnstrm. side of obstruction)
Comment	(additional notes or comments)
Photo Numbers	

Confluence

Bank	(bank on mainstem stream from which tributary stream enters)
Comment	(additional notes or comments)
Photo Numbers	

Observed Sites

Orthophotos and GIS data showing storm water collection systems, outfalls, streams and road crossing locations was provided by the City and used as background information to plan and carry out field investigations.

GIS layers where created for obstruction, erosion, culverts and outlets observed during the field inspection.

The erosion GIS layer contains the locations of observed erosion sites, the severity of the erosion, the length, width, and height of the erosion, and comments or observations of the erosion and causes. See Figure 3-1.

The obstructions GIS layer contains the type of obstruction, the location of the obstruction, whether the obstruction is a barrier in the stream and comments or observations for each obstruction. See Figure3-2.

The culverts and outfalls GIS layers contain the location, material, condition and comments on the condition of the structures. These are summarized in Figure 3-3 and Figure 3-4

Table B-1: Field Inventory - Observed Erosion Sites

Erosion Observations															
SiteID	LOCATION	SEVERITY	CONSQNCE	2011 RISK	2012 RISK	LENGTH	DEPTH	COMMENT	PHOTO_NO	GPS_Date	GPS_Time	Feat_Name	Northing	Easting	Point_ID
147.11	LEFT BANK	LOW	LOW	LOW	LOW	10	1.5	147.11 - Erosion on left bank. No sign of further erosion since 2011 assessment.	486	08/05/2012	08:46:10am	EROSION	5445473.236	511362.804	1
147.10	RIGHT BANK	LOW	LOW	LOW	LOW	20	2	147.10 - Tree at risk of collapse due to undercutting. No sign of further erosion.	487-488	08/05/2012	08:49:04am	EROSION	5445527.121	511327.035	2
147.12	LEFT BANK	LOW	LOW	LOW	LOW	15	1.5	147.12 - No sign of further erosion since 2011 assesment. Site is in a stable condition.	491	08/05/2012	09:02:07am	EROSION	5445591.623	511319.27	5
147.14	LEFT BANK	LOW	LOW	LOW	LOW	NA	NA	147.14 - Blowdown tree in creek. No sign of further erosion since 2011 assesment.	494	08/05/2012	09:08:40am	EROSION	5445628.946	511280.331	7
147.9	LEFT BANK	LOW	LOW	LOW	LOW	50	3.5	147.9 - No sign of further erosion since 2011 assesment.	496-497	08/05/2012	09:17:52am	EROSION	5445767.475	511271.812	9
149.8	RIGHT BANK	LOW	LOW	LOW	LOW	1	1.5	147.8 - Outlet constantly undermined.	499	08/05/2012	09:23:01am	EROSION	5445811.042	511263.562	11
147.4	RIGHT BANK	MODERATE	MODERATE	NEW SITE	MEDIUM	15	2	UNDERCUTTING OF BANK AND TREES, ROAD SETBACK 7M FROM BANK	503-504	08/05/2012	09:35:10am	EROSION	5445843.94	511266.616	13
147.7	RIGHT BANK	LOW	MODERATE	LOW	LOW	50	2	147.7 - EROSION OF RIGHT SIDE OF BANK. 8M SETBACK TO SHED AT TOP BANK	505-507	08/05/2012	09:36:31am	EROSION	5445858.94	511284.4	14
147.6	RIGHT BANK	MODERATE	LOW	MEDIUM	MEDIUM	60	5	147.6 - Collapsed concrete slabs in watercourse. No sign of further erosion since 2011 assesment.	510-511	08/05/2012	09:57:34am	EROSION	5445983.204	511354.432	16
147.5	RIGHT BANK	MODERATE	LOW	LOW	LOW	30	2	147.5 - No sign of further erosion since 2011 assesment.	512-513	08/05/2012	10:02:34am	EROSION	5446028.797	511327.384	17
147.41	RIGHT BANK	MODERATE	MODERATE	NEW SITE	LOW	30	4	Erosion of till bank.	519-520	08/05/2012	10:25:19am	EROSION	5446184.208	511299.729	21
147.42	RIGHT BANK	MODERATE	LOW	NEW SITE	LOW	50	6	Erosion on creek bend, Property setback 40m from bank.	521-523	08/05/2012	10:35:28am	EROSION	5446266.435	511366.019	22
147.16	RIGHT BANK	HIGH	LOW	LOW	LOW	30	1.5	147.16 - Ongoing Erosion, Recently Fallen Trees.	534-535	08/05/2012	12:28:40pm	EROSION	5446446.381	511445.725	28
147.17	RIGHT BANK	MODERATE	MODERATE	MEDIUM	MEDIUM	50	2.5	147.17 - Fence above erosion is at risk. Erosion of bank continuing.	536-537	08/05/2012	12:35:25pm	EROSION	5446476.52	511437.013	29
147.43	LEFT BANK	MODERATE	LOW	NEW SITE	LOW	40	2	OVERHANGING TREE being UNDERCUT	539-540	08/05/2012	01:10:22pm	EROSION	5446752.796	511506.627	31
147.19	LEFT BANK	LOW	MODERATE	MEDIUM	MEDIUM	40	4	147.19 - RECENT EROSION AT BASE OF BANK	542-544	08/05/2012	01:18:28pm	EROSION	5446751.172	511594.509	33
147.22	RIGHT BANK	LOW	LOW	LOW	LOW	30	1.5	147.22 - Trees being undercut. No sign of further erosion since 2011 assesment.	548-547	08/05/2012	01:42:46pm	EROSION	5446836.372	511721.632	35
147.21	RIGHT BANK	LOW	LOW	MEDIUM	MEDIUM	20	1.5	147.21 - Erosion on left and right banks. No sign of further erosion since 2011 assesment.	549-551	08/05/2012	01:46:34pm	EROSION	5446870.409	511751.87	36
147.24	LEFT BANK	MODERATE	LOW	MEDIUM	MEDIUM	60	0.5	147.24 - Private shed and fence are at risk. No sign of further erosion since 2011 assesment.	556	08/05/2012	01:56:22pm	EROSION	5446907.931	511748.732	39
147.23	LEFT BANK	MODERATE	MODERATE	LOW	LOW	40	2	147.23 - Erosion of right bank. No sign of further erosion No sign of further erosion.	557	08/05/2012	02:01:43pm	EROSION	5446947.337	511738.755	40
147.44	RIGHT BANK	LOW	LOW	NEW SITE	LOW	15	1	UNDERCUTTING OF BANK	558	08/05/2012	02:10:25pm	EROSION	5447056.364	511708.409	41
147.45	LEFT BANK	MODERATE	MODERATE	NEW SITE	MEDIUM	15	3	EROSION OF BANK AND UNDERCUTTING OF TREES, PROPERTY SETBACK 20M	559-560	08/05/2012	02:14:49pm	EROSION	5447080.878	511741.178	42
147.46	RIGHT BANK	LOW	LOW	NEW SITE	LOW	20	1	Vertical erosion of bank	561	08/05/2012	02:17:28pm	EROSION	5447103.757	511761.189	43
147.26	LEFT BANK	LOW	LOW	LOW	LOW	30	0.5	147.26 - No sign of further erosion since 2011 assesment.	571-572	08/05/2012	02:50:37pm	EROSION	5447264.905	511759.786	48
147.27	LEFT BANK	LOW	LOW	LOW	LOW	1	1	147.27 - SCOURING UNDER OUTLET IS CONTINUING.	573-574	08/05/2012	02:56:49pm	EROSION	5447364.33	511730.402	49
147.47	LEFT BANK	MODERATE	LOW	NEW SITE	LOW	20	1	Undercutting of tree	575-576	08/05/2012	03:00:19pm	EROSION	5447391.28	511745.605	50
147.3	LEFT BANK	LOW	MODERATE	LOW	LOW	30	1	147.30 - LOG DEBRIS - UNDERCUTTING BANK AND TREE	587-589	09/05/2012	09:03:58am	EROSION	5447745.044	511551.4	57
147.35	LEFT BANK	LOW	LOW	LOW	LOW	12	1.5	147.35 - FURTHER UNDERCUTTING OF TREE, MOST DEBRIS HAS BEEN REMOVED	601,603-605	09/05/2012	09:50:37am	EROSION	5447239.307	512073.496	65
147.48	RIGHT BANK	LOW	MODERATE	NEW SITE	MEDIUM	10	606	UNDERCUTTING TREE - LEANING TOWARDS ROAD	606	09/05/2012	09:55:46am	EROSION	5447254.316	512077.321	66
147.49	BOTH SIDES	MODERATE	HIGH	NEW SITE	HIGH	2	3	EROSION OF BANK ON BOTH SIDES OF CULVERT - HYDRO POLE BEING UNCUT	610-614	09/05/2012	10:13:28am	EROSION	5447324.509	512138.781	69
147.50	RIGHT BANK	MODERATE	LOW	NEW SITE	LOW	20	1	UNDERCUTTING TREES	616-619	09/05/2012	10:17:19am	EROSION	5447330.05	512147.475	70
147.37	RIGHT BANK	LOW	LOW	LOW	LOW	20	,4	147.37 - No sign of further erosion since 2011 assesment.	620-621	09/05/2012	10:23:40am	EROSION	5447362.993	512225.51	71
147.51	RIGHT BANK	MODERATE	LOW	NEW SITE	LOW	40	0.6	Erosion of bank is undercutting trees.	622-623	09/05/2012	10:28:19am	EROSION	5447356.285	512169.07	72
147.36	RIGHT BANK	LOW	LOW	LOW	LOW	15	1	147.36 - Erosion of right bank. No sign of further erosion since 2011 assesment.	624-626	09/05/2012	10:36:34am	EROSION	5447395.577	512248.839	73
147.38	LEFT BANK	LOW	LOW	LOW	LOW	NA	NA	147.38 - Blowdown. No sign of further erosion since 2011 assesment.	635	09/05/2012	10:57:31am	EROSION	5447568.31	512319.141	79
147.31	MID CHANNEL	LOW	LOW	LOW	LOW	1	2	147.31 - No sign of further erosion since 2011 assesment.	658	09/05/2012	01:22:37pm	EROSION	5447028.24	511213.528	90
147.52	LEFT BANK	LOW	LOW	NEW SITE	LOW	50	2	Vertical Bank - Recently Eroded or Widened	664-666	09/05/2012	01:46:37pm	EROSION	5446841.13	511290.39	94
147.53	RIGHT BANK	LOW	LOW	NEW SITE	LOW	20	1.5	Undercutting of bank	667	09/05/2012	01:50:37pm	EROSION	5446814.618	511321.205	95
147.54	RIGHT BANK	MODERATE	MODERATE	NEW SITE	MEDIUM	50	1.5	Undercutting of bank	668	09/05/2012	01:52:43pm	EROSION	5446818.434	511342.189	96
147.55	RIGHT BANK	MODERATE	HIGH	NEW SITE	HIGH	20	1.5	UNDERCUTTING OF TREE - MAY HIT NEW PROPERTY DEVELOPMENT	669-670	09/05/2012	01:54:49pm	EROSION	5446813.184	511349.668	97
147.56	LEFT BANK	LOW	MODERATE	NEW SITE	LOW	10	1	UNDERCUTTING OF TREE - PROPERTY SETBACK 10M FROM RIGHT BANK	671	09/05/2012	02:02:55pm	EROSION	5446756.801	511373.304	98

Table B-3: Field Inventory - Observed Culvert Inlet Sites

Culvert Inlet Points																
SiteID	DIAMETER	MATERIAL	CONDITN	HEADWALL	HW_CNDTN	BARRIER	OVRFL_HT	SED_DPTH	COMMENT	PHOTO_NO	GPS_Date	GPS_Time	Feat_Name	Northing	Easting	Point_ID
147.80	1.8X1.5	CONCRETE	GOOD	CONCRETE WALL	GOOD	NO	3	0		582	09/05/2012	08:38:40am	CULV_IN	5447615.72	511622.846	53
147.29	3X3	CONCRETE	GOOD	CONCRETE WALL	GOOD	NO	3	0.2	147.29 - Shopping cart blocking inlet structure.	600	09/05/2012	09:34:31am	CULV_IN	5447597.951	511616.735	63
147.35B	1.35	CONCRETE	GOOD	CONCRETE WALL	GOOD	YES	3	0	147.35B - Most of the debris at the grate, identified in 2011 has been removed	602	09/05/2012	09:48:49am	CULV_IN	5447233.76	512072.73	64
147.81	1.05	CONCRETE	GOOD	CONCRETE WALL	GOOD	YES	3	0.2	DEBRIS ON GRATE	640-641	09/05/2012	12:37:34pm	CULV_IN	5447167.945	510974.631	82
147.82	1.5	CMP	GOOD	CONCRETE WALL	GOOD	NO	1.5	0		645-647	09/05/2012	12:44:07pm	CULV_IN	5447084.988	510997.559	84
147.83	NA	CONCRETE	POOR	NA	NA	NA	6	NA	CULVERT INLET BLOCKED WITH DEBRIS, CAUSING STAGNATION UPSTREAM	650	09/05/2012	12:53:52pm	CULV_IN	5446998.882	511055.603	86
147.84	1.5	CONCRETE	GOOD	CONCRETE BAGS	GOOD	NO	8	0	147.31 - Small amount of floating debris in culvert inlet.	659-660	09/05/2012	01:23:49pm	CULV_IN	5447030.784	511212.121	91
147.85	1.8 X 1	CONCRETE	GOOD	CONCRETE WALL	GOOD	NO	0.5	0	PRIV BRIDGE/BOXED CULVERT	672-673	09/05/2012	02:06:28pm	CULV_IN	5446734.516	511392.757	99

Table B-4: Field Inventory - Observed Culvert Unlet Sites

Culvert Inlet Points																
SiteID	DIAMETER	MATERIAL	CONDITN	HEADWALL	HW_CNDTN	BARRIER	OVRFL_HT	SED_DPTH	COMMENT	PHOTO_NO	GPS_Date	GPS_Time	Feat_Name	Northing	Easting	Point_ID
147.91	2 X 2.5	CONCRETE	FAIR	NONE - PROJECTING	NA	NONE	0.2	0	THE BASE OF THE CULVERT IS CORRODING NEAR THE OUTLET	554	08/05/2012	01:52:28pm	CULV_OUT	5446882.51	511751.83	38
147.92	2 X 2	CONCRETE	GOOD	CONCRETE WALL	GOOD	CONCRETE WAL	0.5	0	OUT KING GEORGE	579-581	08/05/2012	03:13:34pm	CULV_OUT	5447530.58	511664.523	52
147.93	5 X 3	CONCRETE	GOOD	LOCKBLOCKS	GOOD	NONE	0	0	CULVERT UNDER SKYTRAIN ST	584-585	09/05/2012	08:52:46am	CULV_OUT	5447704.021	511537.149	55
147.94	0.6	CONCRETE	GOOD	ROCKSTACK	FAIR	RIPRAP	0	0.3	HALF OF PIPE BURRIED BELOW WATERLINE - OUTFALL FROM DETENTION POND	586	09/05/2012	09:01:13am	CULV_OUT	5447720.488	511530.637	56
147.95	NA	CONCRETE	BLOCKED	ROCKSTACK	GOOD	NONE	0	0	BURRIED BELOW WATERLINE, POND LOOKS STAGNANT	596-597	09/05/2012	09:20:46am	CULV_OUT	5447820.035	511487.122	61
147.96	1.5 X 1.1	CONCRETE	GOOD	CONCRETE WALL	GOOD	NONE	0.7		147.34 - Erosion of left and right bank walls. No sign of further erosion since 2011 assessment.	607-608	09/05/2012	09:59:22am	CULV_OUT	5447296.12	512117.287	67
147.97	1.4	CONCRETE	GOOD	CONCRETE WALL	GOOD	RIPRAP	0.2	0	CULVERT UNDER NEW ROAD	627	09/05/2012	10:38:16am	CULV_OUT	5447406.897	512274.238	74
147.98	1.8 X .9	CONCRETE	GOOD	CONCRETE WALL	GOOD	RIPRAP	0	0	CULVERT UNDER NEW ROAD - CULVERT HALF FILLED WITH RIPRAP	630-631	09/05/2012	10:43:55am	CULV_OUT	5447438.497	512298.636	76
147.99	1	CONCRETE	GOOD	NONE - PROJECTING	NA	NONE	0.3	0	CULVERT UNDER PRIV BRIDGE	639	09/05/2012	12:35:04pm	CULV_OUT	5447181.133	510950.978	81
147.100	1.1	CONCRETE	GOOD	CONCRETE WALL	GOOD	CONCRETE WAL	0	0	CULVERT UNDER 96TH AVE	642-643	09/05/2012	12:41:31pm	CULV_OUT	5447134.274	510997.031	83
147.101	1.6	CMP	GOOD	GABION BOXES	GOOD	NONE	0	0		649	09/05/2012	12:49:16pm	CULV_OUT	5447053.106	511023.499	85
147.102	1.2	CMP	FAIR	CONCRETE BAGS	NONE - PROJECTING	RIPRAP	0.2	0		653	09/05/2012	12:59:40pm	CULV_OUT	5446951.806	511108.95	87
147.103	0.6	CONCRETE	FAIR	CONCRETE BAGS	FAIR	NONE	0	0	70% OF OUTLET BELOW WATER LINE	656	09/05/2012	01:13:22pm	CULV_OUT	5447120.549	511158.98	89
147.104	1.7	CONCRETE	GOOD	CONCRETE BAGS	GOOD	NONE	0	0.5		661	09/05/2012	01:29:43pm	CULV_OUT	5446967.617	511261.046	92
147.105	1.2	CONCRETE	GOOD	CONCRETE WALL	GOOD	NONE	0.2	0		662	09/05/2012	01:35:49pm	CULV_OUT	5446869.161	511294.439	93

Table B-2: Drainage Inventory - Observed Obstruction Sites

Obstruction Observations															
SiteID	CAUSE	STABILTY	2011_Risk	2012_Risk	TYPE	D_S_DROP (m)	COMMENT	PHOTO_NO	GPS_Date	GPS_Time	Feat_Name	Northing	Easting	Point_ID
147.13	NATURAL	STABLE	LOW	LOW	LOG	0.3	147.13 - Debris jam comprised of logs and sticks.	492-493	41037	09:04:10am	OBSTRCTN	5445596.47	511308.992	6
147.57	NATURAL	STABLE	NEW SITE	LOW	LOG	0.3	Fallen log restricting flow	495	41037	09:11:31am	OBSTRCTN	5445637.32	511271.408	8
147.58	NATURAL	UNSTABLE	NEW SITE	LOW	LOG	0	Fallen log restricting flow on left hand side	518	41037	10:19:43am	OBSTRCTN	5446148.82	511306.449	20
147.59	NATURAL	STABLE	NEW SITE	LOW	LOG	0	Fallen log restricting flow	524-525	41037	10:41:37am	OBSTRCTN	5446277.87	511388.602	23
147.15	NATURAL	STABLE	LOW	LOW	LOG	0	147.15 - Large tree restricting flow	533	41037	12:25:25pm	OBSTRCTN	5446417.84	511449.958	27
147.60	NATURAL	UNSTABLE	NEW SITE	LOW	DEBRIS	0	Build up of debris restricting flow	545-546	41037	01:39:40pm	OBSTRCTN	5446820.75	511686.048	34
147.61	NATURAL	UNSTABLE	NEW SITE	LOW	PONDING	0	Debris restricting flow in MANMADE OFF CHANNEL POND	568-570	41037	02:36:04pm	OBSTRCTN	5447169.16	511752.859	47
147.28	NATURAL	STABLE	LOW	LOW	LOG	0.75	147.28 - Log jam with shopping cart	577-578	41037	03:03:40pm	OBSTRCTN	5447406.54	511748.818	51
147.62	NATURAL	UNSTABLE	NEW SITE	LOW	LOG DEBRIS	0	Log jam	583	41038	08:44:10am	OBSTRCTN	5447644.68	511579.85	54
147.63	ANTHROPOGENIC	STABLE	NEW SITE	LOW	RIPRAP	0	Riprap barrier between stagnant pond and manmade channel	591-593	41038	09:15:34am	OBSTRCTN	5447820.49	511483.991	59
147.64	ANTHROPOGENIC	STABLE	NEW SITE	LOW	BLOCKED CULVERT	0	Seal culvert preventing flow to detention pond	594-595	41038	09:18:37am	OBSTRCTN	5447830.85	511482.685	60
147.65	NATURAL	UNSTABLE	NEW SITE	LOW	DEBRIS ON GRATE	0	Debris build up on grate restricting flow	628	41038	10:41:25am	OBSTRCTN	5447409.77	512293.086	75
147.66	NATURAL	UNSTABLE	NEW SITE	LOW	WOOD DEBRIS	0	Debris build up on grate	632	41038	10:48:01am	OBSTRCTN	5447478.42	512294.372	77
147.67	ANTHROPOGENIC	UNSTABLE	NEW SITE	LOW	FALLEN PRIV BRIDGE	0	Collapsed private foot bridge	633	41038	10:51:55am	OBSTRCTN	5447519.35	512303.245	78

Table B-5: Field Inventory - Observed Bridge Sites

Bridges													
SiteID	LENGTH	SPAN	HEIGHT	THCKNESS	CONDITION	COMMENT1	PHOTO_NO	GPS_Date	GPS_Time	Feat_Name	Northing	Easting	Point_ID
147.86	25	12	2.5	0.8	GOOD		489	08/05/2012	08:52:01am	BRIDGE	5445548.49	511316.515	3
147.87	8	4	4	0.6	GOOD		498	08/05/2012	09:21:31am	BRIDGE	5445794.17	511270.5	10
147.88	3	1.8	1	0.3	GOOD	PRIVATE FOOT BRIDGE	538	08/05/2012	12:57:37pm	BRIDGE	5446723.44	511396.418	30
147.89	3	1.5	1.5		GOOD	PRIVATE GARDEN BRIDGE	562	08/05/2012	02:21:16pm	BRIDGE	5447115.51	511785.691	44
147.9	27	4.5	2	2	GOOD	96 AVE BRIDGE	567	08/05/2012	02:26:43pm	BRIDGE	5447126.46	511792.066	46

Table B-6: Field Inventory - Observed Outfall Sites

Storm Outfalls to Creek																	
Site_ID	BANK	DIAMETER	MATERIAL	CONDITN	ENRG_DIS	HEADWALL	HW_CNDTN	OUT_DROP	SED_DPTH	COMMENT	PHOTO_NO	GPS_Date	GPS_Time	Feat_Name	Northing	Easting	Point_ID
147.68	RIGHT	0.6	CONCRETE	GOOD	RIPRAP	CONCRETE WALL	GOOD	0	0	2M DROP TO CREEK	500-502	08/05/2012	09:26:49am	OUTFALL	5445850.644	511266.033	12
147.69	LEFT	0.3	CONCRETE	NA	NA	NA	NA	0	0	MANHOLE SURROUNDED WITH GABION BASKETS, CANT FIND OUTFALL, LID WET, MAYBE AN OVERFLOW	508-509	08/05/2012	09:53:58am	OUTFALL	5445977.17	511340.469	15
147.70	LEFT	0.3	CONCRETE	GOOD	RIPRAP	CONCRETE WALL	GOOD	0	0		514-516	08/05/2012	10:07:25am	OUTFALL	5446068.073	511317.289	18
147.71	LEFT	0.6	CONCRETE	FAIR	RIPRAP	NONE - PROJECTING	NA	1.5	0	LARGE DROP TO CREEK , PIPE SLIGHTLY DAMAGED	527-528	08/05/2012	10:54:34am	OUTFALL	5446363.208	511466.157	24
147.72	RIGHT	0.3	CONCRETE	FAIR	RIPRAP	NONE - PROJECTING	NA	0	0		529	08/05/2012	10:57:52am	OUTFALL	5446365.501	511469.784	25
147.73	RIGHT	0.6	CONCRETE	GOOD	RIPRAP	NONE - PROJECTING	NA	0.5	0		531-532	08/05/2012	12:22:58pm	OUTFALL	5446392.885	511453.915	26
147.74	LEFT	0.3	HDPE	GOOD	RIPRAP	NONE - PROJECTING	NA	1	0		541	08/05/2012	01:14:34pm	OUTFALL	5446758.742	511531.765	32
147.75	LEFT	0.3	OTHER	FAIR	NONE	NONE - PROJECTING	NA	0.5	0	PIPE IS CRACKED AT OUTLET	552-553	08/05/2012	01:49:16pm	OUTFALL	5446881.863	511755.998	37
147.76	LEFT	1.2	CMP	GOOD	RIPRAP	ROCKSTACK	FAIR	0.2	0		563-565	08/05/2012	02:23:40pm	OUTFALL	5447127.832	511795.776	45
147.77	CENTER	3M	CONCRETE	FAIR	NONE	CONCRETE WALL	GOOD	0	0	QUIBBLE CREEK BEGINS AT THIS OUTFALL, WATER IS STAGNANT	598-599	09/05/2012	09:25:31am	OUTFALL	5447870.967	511454.88	62
147.78	RIGHT	0.75	CONCRETE	GOOD	RIPRAP	CONCRETE WALL	GOOD	0	0		609	09/05/2012	10:11:19am	OUTFALL	5447325.315	512131.798	68
147.79	RIGHT	0.75	CONCRETE	GOOD	NONE	CONCRETE WALL	GOOD	0.2	0		636-637	09/05/2012	12:30:01pm	OUTFALL	5447213.974	510935.136	80

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Appendix C

Environmental Inventory and Assessment

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Quibble Creek Watershed Report Card

1. General Characteristics	
Watershed Area / Urban Watershed Area	656 ha / 578 ha (89%)
Stream Channel Length / Length with Fish	6.5 km / 3.7 km (56%)
Stream Channel Density	1.0 km/km^2
Max / Min Elevation	112 m / 26 m
Watershed Slope	2%
Annual Precipitation	1,500 mm/yr (Surrey City Centre)
2. Land Cover	
Total Imperviousness (%)	67.7%
Riparian Forest Cover (%)	60% (22.4 ha of 37.4 ha) in 2011
Watershed Forest Cover (%)	13% (86.6 ha) in 2011
Road density	9.8 km/km^2
Road crossings	13 crossings (including bridges and culverts)
3. Land Use (2006 Metro Vancouver)	
Park and Open Space	125 ha (19%)
Single-family Residential	279 ha (43%)
Multi-family and High Density Residential	69 ha (11%)
Commercial and Institutional	139 ha (21%)
Transportation	41 ha (6%)
4. Fish Populations	
Confirmed present: Coho salmon, Chum salmon, Cutthroat trout (resident), Western brook lamprey, Threespine stickleback	
Possibly/historically present: Sculpin species, Steelhead trout, Chinook salmon	
6. Benthic Invertebrate Community	
B-IBI (2009-2012)	14.1 (Very Poor)
Benthic Taxa Richness (2009-2012)	6.7
EPT Taxa Richness (2009-2012)	1.1
7. Hydrology	
Average Discharge (Q_m)	0.22 m3/s
Min Summer Discharge (7-day low flow)	0.0055 m3/s
Max Storm Discharge (Q_{max})	17.27 m3/s
8. Available Monitoring Data	
Discharge (Stage)	Quibble Creek @ 88th Ave
Precipitation	1 site at 104 m asl (mean: 1,500 mm/yr)
Benthic Invertebrates	Annual spring sampling since 2009
Water Quality	General survey in June 2012
Sediment sampling	Total metals at one site in 2012; no metals above BCWSQ Guidelines

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Summary of Environmental Values and Issues

- Quibble Creek is remarkable because of good quality instream and riparian habitat despite the high level of urbanization. Kistritz (1998) stated that "Quibble Creek is a contradiction" where ecological conditions are not consistent with watershed urbanization. The forested riparian corridor is likely an important factor sustaining ecological health. Hydrologic resilience related to groundwater infiltration may also be important.
- A total of 86.6 ha (13%) of the Quibble Creek watershed was forested in 2011. Concentrations of forest are found in the Green Timbers area and the Quibble Creek riparian corridor. Approximately 20.1 ha (3%) of watershed forest cover have been lost since 1995.
- The riparian area is relatively intact and continuous except for major road crossings. Approximately 60% (22.4 ha) of the Quibble Creek riparian zone is currently forested, mainly with deciduous forest. Riparian forest cover has remained stable over the past 16 years (22.5 ha in 2011 and 22.4 ha in 1995) largely because of regulation of development in riparian areas. Invasive plants are common in riparian areas.
- Good quality instream habitat supports spawning and rearing habitat for wild coho salmon, chum salmon, and cutthroat trout. In November 2012, 122 adult coho and 537 adult chum were observed spawning in Quibble Creek, mainly in the mainstem. Fish sampling and observations confirmed the City of Surrey's watercourse classification for Quibble Creek based on fish distribution.
- Fish passage is not a major concern (predominantly bridges and fish passable culverts) for fish populations in the mainstem but do limit fish use of tributary streams.
- Mean bankfull width in the Quibble Creek mainstem in May 2012 was 6.0 m and wetted width was 4.5 m. Instream substrate is predominantly cobble and gravel with lesser amounts of boulder and fine sediment (sand and silt).
- A total of 210 pieces of large wood were recorded with an average length of 8.5 m, diameter of 35 cm and volume of 0.91 m^3. The density of large instream wood was 3.2 pieces per 100 m of stream channel which indicates that Quibble Creek is relatively barren of large instream wood compared to natural streams.
- Fifty-two pools deeper than 40 cm deep were measured in May 2012. There was no clear pattern or concentration of pool development.
- Low summer flows are not an important limiting factor for fish population sin Quibble Creek but do affect smaller tributary streams.
- The limited water quality survey found conditions typical of urbanized streams in Metro Vancouver. Total metals in sediment collected from one site in lower Quibble Creek were lower than BC Sediment Quality Guidelines, and lower than other urban streams in Metro Vancouver.
- Mean B-IBI for all samples as 14.1 which is consistent with the high level of urbanization in the watershed. It indicates very poor condition. B-IBI was very stable over the 3 years of sampling. Mean taxa (all invertebrates sampled) richness for all samples was 6.7 and mean EPT taxa richness (stoneflies, mayflies, caddisflies) was 1.1 (range of 1 to 2). Both metrics indicate very poor stream condition.
- Restoration and enhancement opportunities were identified that focus on four components: (1) landscape-level connections including forest protection or restoration that support the City's green infrastructure network; (2) riparian restoration and management that focuses on increasing the amount and function of riparian forest; (3) instream and off-channel habitat restoration to enhance fish populations; and (4) improvements to fish passage.

Appendix C – Environmental Inventory and Assessment

Introduction and Purpose

An environmental inventory of the Quibble Creek watershed was undertaken to summarize information on water and sediment quality, benthic invertebrate communities, fish and fish habitat, channel conditions, and vegetation and land cover patterns. In addition, habitat restoration sites and enhancement strategies focusing on instream and riparian areas were also identified.

There is relatively little specific information on fish and fish habitat, water quality, and other components of the ecological health of Quibble Creek. Two reports provide useful information. Kistritz (1995)[1] completed a biophysical inventory of channel conditions and fish habitat as part of a development application. A more comprehensive review of environmental conditions including erosion, sedimentation, fish passage, and other limitations to fish populations was undertaken by Kistritz in 1998[2] as a component of the Bear Creek Master Drainage Plan. Other reports include the 2008 Surrey Ravine Study by Associated Engineering, the 2011 Green Infrastructure Network analysis by HB Lanarc and Raincoast Applied Ecology, and annual reports on the City of Surrey's benthic invertebrate monitoring program[3].

The 1998 Kistritz report provided a succinct summary of urbanization related issues affecting the ecological value of Quibble Creek. It noted that Quibble Creek had good quality spawning and rearing habitat for fish, had barriers to fish passage, did not have summer low flow problems, did not have sedimentation problems, did not have major areas of erosion, and did have water quality problems. These same attributes describe the condition of Quibble Creek in 2013.

It also stated that Quibble Creek had surprisingly good riparian and instream habitat relative to other streams in the Bear Creek watershed. It noted that "Quibble Creek is a contradiction" where ecological conditions were not consistent with the level of watershed urbanization. This assessment also noted this unique characteristic of Quibble Creek, but did not find a specific reason or groups of factors to explain it. The 2012 assessment supports this finding that habitat quality is higher than expected based on watershed imperviousness. The forested riparian corridor is likely an important factor sustaining ecological health. Hydrologic resilience related to groundwater infiltration may also be important.

Watershed and Riparian Forest Cover

Forest vegetation and forest soils regulate many important watershed processes, such as the movement and provision of water, sediment, nutrients, organic matter, and wood. Within watersheds, forests are important regulators of streamflow through rainfall interception, capture, and evapotranspiration, and forest soils infiltrate, store, and transport water. Forests within the riparian area, the interface zone between the water and land, also protect streams by providing cooling shade and stabilizing banks, as well as supplying food, nutrients, organic matter, and instream wood debris that are important components of aquatic ecosystems and fish habitat. Both

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[1] Kistritz, R.U. 1995. Bioinventory and habitat enhancement assessment of Quibble Creek. Unpublished report prepared by R.U. Kistritz Consultants for Dynamics Maintenance and William Rhone Architects. 20 pp.

[2] Kistritz, R.U. 1998. City of Surrey Bear Creek MDP: Technical Working Paper No. 3: Fish habitat assessment and management implications. Unpublished report prepared by R.U. Kistritz Consultants with KWL Associates and CH2M-Hill for City of Surrey. 90 pp.

[3] Raincoast Applied Ecology. 2011. 2010 City of Surrey benthic invertebrate monitoring program: methods and results. Unpublished report prepared for City of Surrey Engineering Department. 378 pp.

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watershed and riparian forest cover decline with increasing urbanization. Watershed forest cover may also be a useful indicator of the increasing intensity of urban land use in situations where imperviousness remains relatively stable.

Watershed and riparian forest cover was assessed to measure the amount and distribution of tree canopy cover within the Quibble Creek watershed and to identify areas for potential riparian forest restoration. Watershed and riparian forest cover was mapped using 2011 and 1995 orthophotos in GIS based on visual interpretation of current forest cover and its change over the past 16 years. It included large forest patches as well as smaller patches distributed within urban areas and parks.

Riparian forest cover mapping followed methods followed those used by Page and Johnston (2006). A standard 30 m buffer on either side of the centerline of permanent stream channels (60 m total width) was used to assess riparian forest integrity (RFI) across the watershed. RFI has been used as an indicator of riparian function in urbanizing watersheds in Metro Vancouver as part of ISMP planning[4].

Figures C-1 and C-2 provide a graphical summary of watershed and riparian forest cover mapping. Key findings of the analysis were:

- A total of 86.6 ha (13%) of the Quibble Creek watershed was forested in 2011. Concentrations of forest are found in the Green Timbers area and the Quibble Creek riparian corridor.
- Approximately 20.1 ha (3%) of forest cover have been lost in the past 16 years based on 106.8 ha (16%) of watershed forest cover in 1995. The largest losses occurred during development of Holland Park and the creation of Creekside Elementary School.
- Approximately 60% (22.4 ha) of the Quibble Creek riparian zone is currently forested. The riparian area is relatively intact and forms a continuous band except for major road crossing. Most of the riparian area is vegetated with deciduous forest (red alder and black cottonwood).
- Riparian forest cover has remained stable over the past 16 years (22.5 ha in 2011 and 22.4 ha in 1995) largely because of regulation of development in riparian areas. At the same time, restoration and enhancement projects focusing on riparian habitat have not increased riparian forest substantially.

[4] Greater Vancouver Regional District. 2005. Template for Integrated Stormwater Management Planning 2005. Draft report produced by Kerr Wood Leidal Associates for Greater Vancouver Regional District, December 2005.

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Figure C-1: Diverse riparian forest along Quibble Creek mainstem.

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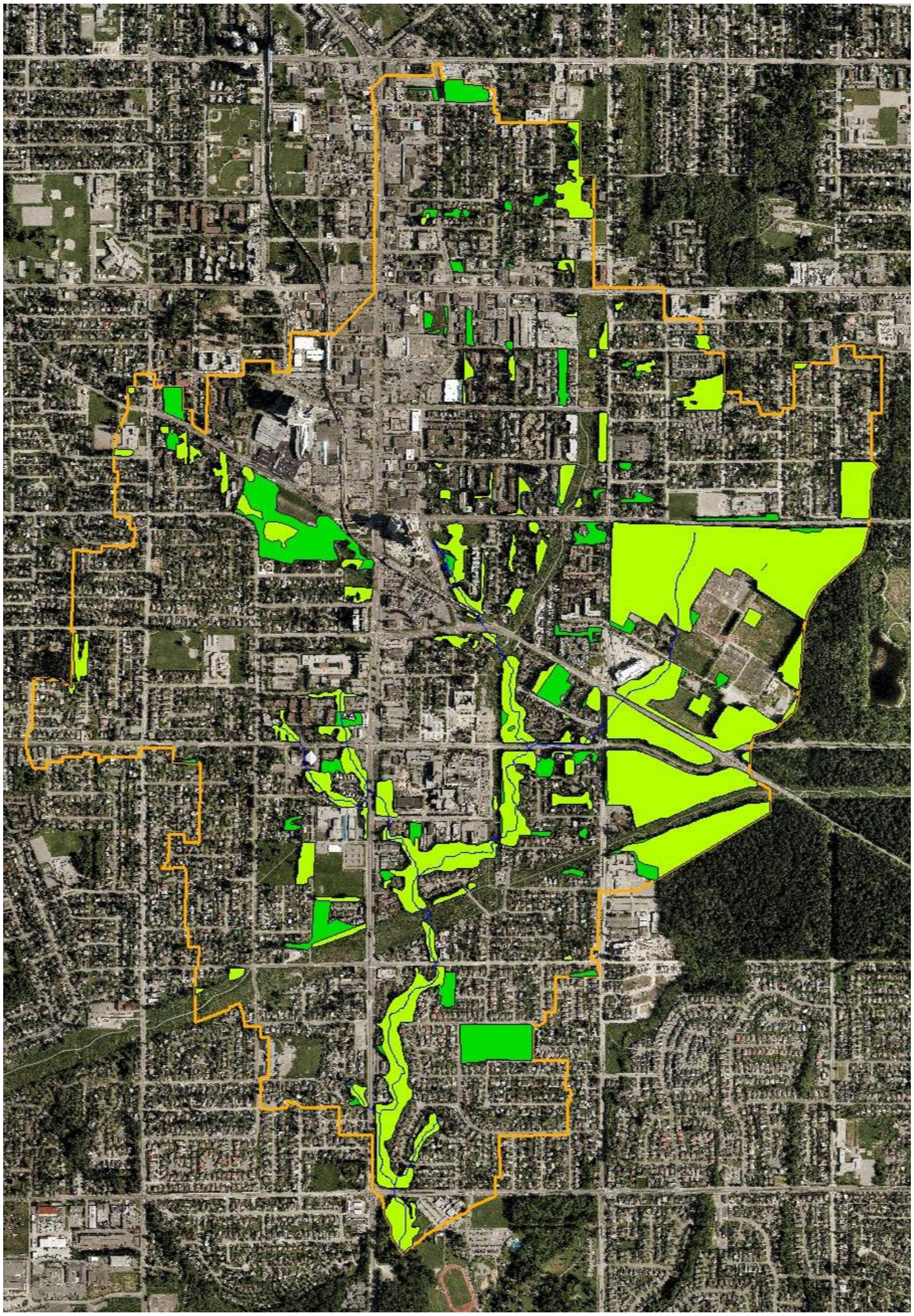

Figure C-2: Watershed forest cover in 2011 (yellow green) and losses since 1995 (green).

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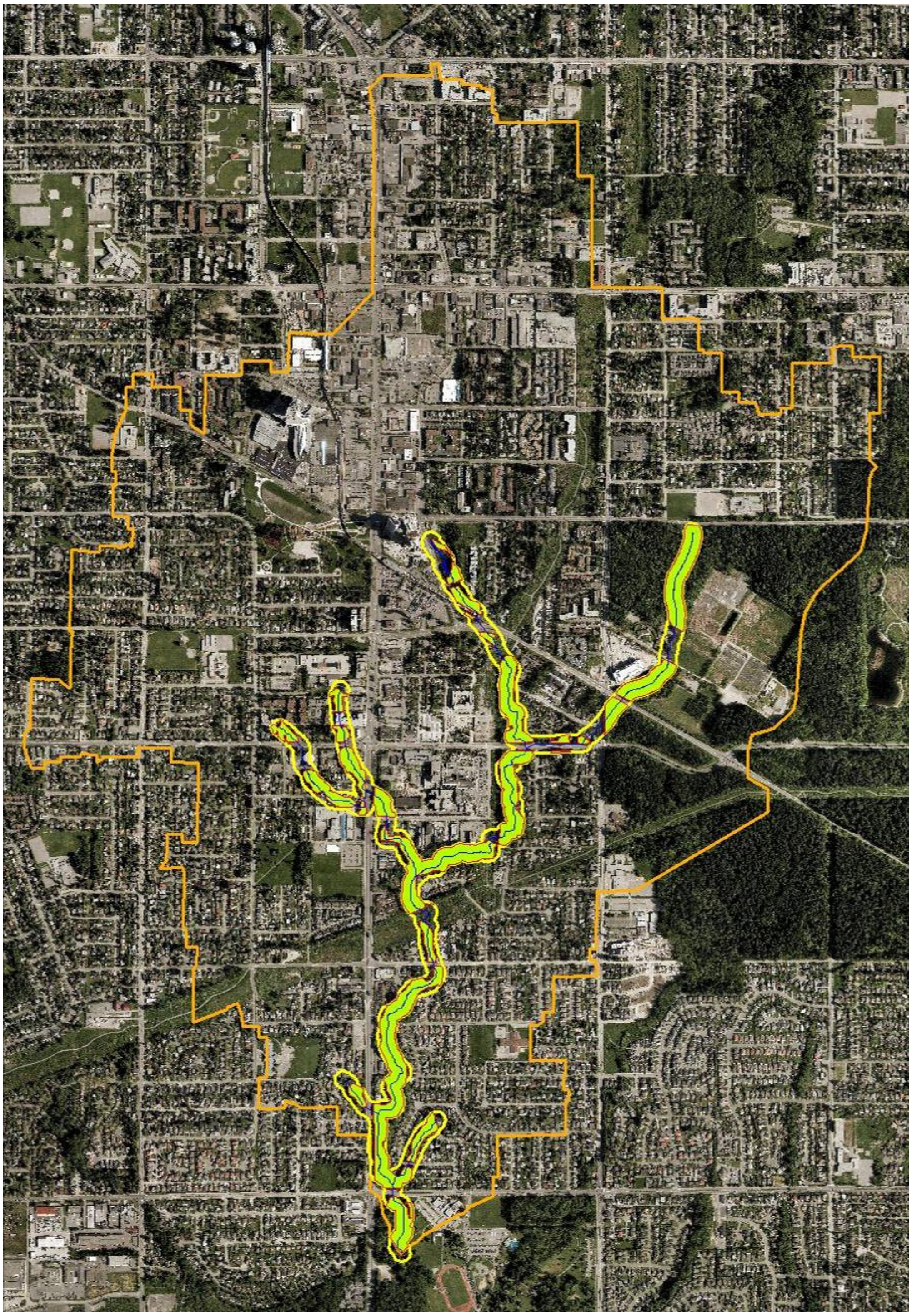

Figure C-3: Riparian forest cover (%RFI) in Quibble Creek watershed.

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Water and Sediment Quality

Water quality refers to the chemical, physical and biological conditions of water and the degree to which it is impaired or degraded by natural or anthropogenic factors. Water quality in streams is vital to the protection of ecosystem functions and aquatic life, such as fish, as well as human uses for drinking water and recreation, and aesthetics. Comparisons to BC Water Quality Guidelines (BCWQGs) and the Canadian Water Quality Guidelines for the Protection of Aquatic Life (CWQGs) can help to assess whether current stormwater management is adequately protecting these values. Sediment quality can also contribute to understanding stream condition and provide a baseline for measuring trends over time.

There is little information on water quality in Quibble Creek except for anecdotal information in Kistritz (1995; 1998). He commented in the 1998 report that the large stormwater outfall from the catchment north of 100 Ave was an important contributor of poor water quality, and that the existing pond and wetland at that location could be used improve water quality. However, no data was presented on water quality at the site. A wetland was constructed by City of Surrey to remove sediment and associated contaminants from urban runoff [need more info on this wetland].

Three methods were used to assess water and sediment quality in the Quibble Creek watershed: (1) a survey of general water quality parameters throughout the watershed (e.g., temperature, pH); (2) monitoring of water temperature at two sites in spring and summer 2012; and (3) a single sediment sample collected in lower Quibble Creek in Bear Creek Park. More detailed water quality analysis for nutrients, metals, and other parameters was not undertaken.

General Water Quality Survey. In-situ measurements of general water quality parameters (temperature, specific conductivity, DO, pH, oxygen reduction potential (ORP), and turbidity) were undertaken throughout the watershed during low flow conditions on June 21, 2012 (40 sites in total). A YSI 6920 multi-parameter probe was used to measure parameters at 40 sites including mainstem, tributaries, and stormwater outfalls. Sites sampled are illustrated on Figure 4-1.

Table C-1: Minimum, maximum, and mean values for general water quality parameters measured in the Quibble Creek watershed on June 21, 2012.

Parameter	Units	Parameter Values		
		Minimum	Maximum	Mean
Water Temperature	°C	13.0	17.7	14.5
Dissolved Oxygen	mg/L	8.9	22.0	12.1
Specific Conductivity	μS/cm	187	746	327
pH	pH units	5.46	8.29	7.67
Turbidity	NTU	0.6	67.5	3.7
Oxygen Reduction potential (ORP)	-	-5.46	8.29	7.67

Key results of the water quality survey were:

- The survey did not find any specific sites or stream sections with elevated or unusual water quality characteristics which would indicate specific sources of contaminations (e.g., “hot spots”). Measurements of general water quality parameters were consistent with regional observations in urban streams.

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- Specific conductivity was elevated (mean of 327 uS/cm) relative to undisturbed streams (typically <20 uS/cm), however, it was consistent with other heavily urbanized streams such as Still Creek in Vancouver and Wagg Creek in North Vancouver.
- Dissolved oxygen levels were generally above 10 mg/L which is suitable for salmonid spawning and rearing.
- pH ranged from 5.47 to 8.29 (mean of 7.67) which is more variable than some watersheds but still within expected ranges.
- Turbidity was low (mean of 3.7 NTU) but elevated at one storm outfall (67.5 NTU). If this measurement was removed, the mean turbidity was 2.1 NTU.

Instream Temperature Monitoring. Temperature probes (Onset Hobo) were installed at two locations in the mainstem of Quibble Creek: (1) downstream of the stormwater pond south of 100 Ave (2) below 88 Ave in Bear Creek Park. Each probe recorded water temperature every 15 minutes. They were installed on April 28 and were retrieved on September 4, 2012. The battery in the upstream probe failed on June 14 and missed the expected peak in summer temperature. Figure C-4 provides a graphical summary of temperature change in the spring and summer in 2012.

Water temperature monitoring showed two noteworthy results:

- During the period where both probes were operational, water temperature was often 0.8 to 1.7 degree higher at the upstream monitoring site. This was expected based on the lack of shading provided by the regenerating riparian forest. However, it is an unusual pattern as most headwater streams are cooler and better shaded than downstream sections.
- The maximum temperature in the summer of 2012 was around 20^{o}C at the downstream monitoring site and by extrapolation was likely close to 22^{o}C at the upstream site. This is higher than the recommended range for salmonid habitat but below levels which cause mortality. However, these values are not considered unusual for urban streams in Metro Vancouver.

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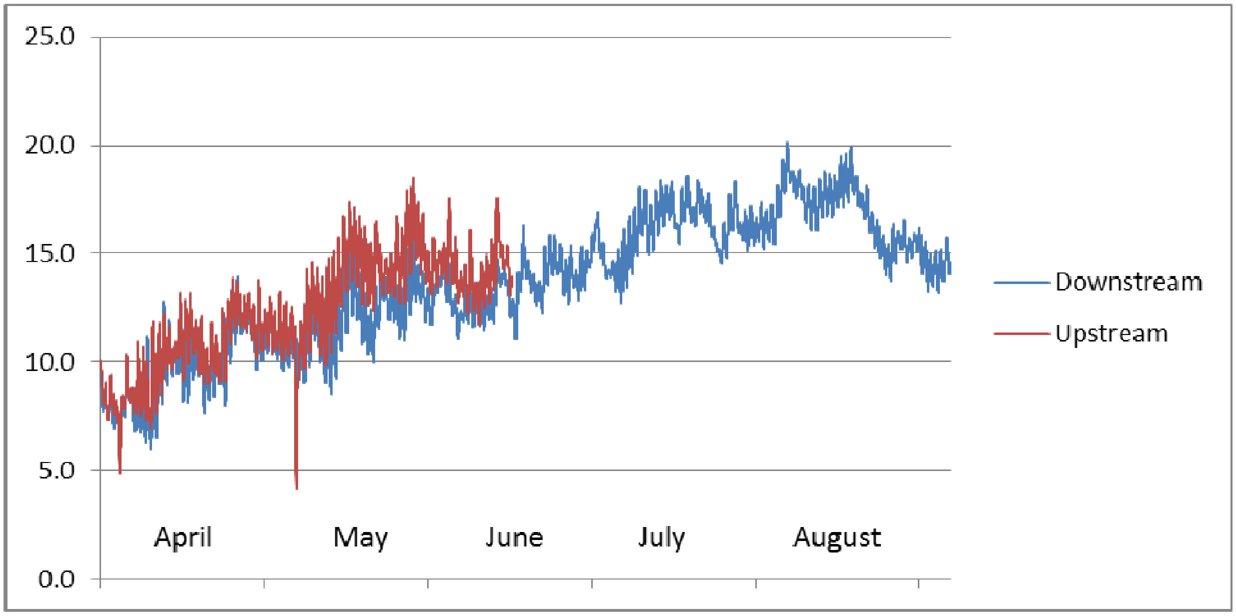

Figure C-4: Summary of water temperature monitoring in Quibble Creek (April to September 2012) (upstream site downstream of pond at 100 Ave and downstream site in Bear Creek Park (below 88 Ave)).

Sediment Quality Sampling. Stream sediments accumulate metals and other contaminants from a variety of sources in developed watersheds, and provide a complimentary assessment of environmental chemistry when combined with water quality. They are also useful for long-term monitoring of stream condition because they are much less variable than water quality measurements. Concentrations of total metals in stream sediments can be compared to BC Working Sediment Quality Guidelines (BCSQGs) and regional studies.

One sediment sample was collected on November 11, 2012 from the lower section of Quibble Creek in Bear Creek Park. The sample was composite of surface and shallow sub-surface fine sediment collected from 10–15 sites from within the active stream channel. The sampling location is shown in Figure 2-10. The sample was analyzed for total metals using BC CSR standard methods.

Key results were:

- No metals were above BC Working Sediment Quality Guidelines (BCSQGs).
- Total metals in Quibble Creek sediment were generally lower than other urban watersheds in Metro Vancouver. This result was unexpected given the level of urbanization in the Quibble Creek watershed.

Full sediment quality sampling data can be found in Figure 4-1.

Benthic Invertebrates

The City of Surrey has sampled benthic (streambed) invertebrates throughout the city's streams since 1999 as a monitoring tool for tracking changes to stream health. One site in lower Quibble Creek (downstream of 88 Ave in Bear Creek Park; see Figure C-6 for location) has been sampled six times since 2009 (spring and fall in 2009 and 2010; spring only in 2011 and 2012). It will continue to be sampled during the spring.

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Samples are collected using a field sampling protocol developed for City of Surrey by Dillon Consulting[5]: three non-composited samples are collected from each site using a 250 micron Surber sampler. Samples are collected from adjacent riffles using 2 minutes of substrate disturbance. Sample processing, subsampling, taxonomic identification, and B-IBI scoring (used as an index of watershed health) was completed by Rhithron Associates (Missoula, MT).

Analysis of the available benthic invertebrate data found the following points:

- Mean B-IBI for all samples as 14.1 which is consistent with the high level of urbanization in the watershed: high total impervious area and reduced riparian forest are linked to low B-IBI scores. B-IBI ranges from 10 to 50 and a mean score of 14.1 indicates very poor condition.
- B-IBI was very stable over the 3 years of sampling (see Figure C-5): 17 of 18 samples had a B-IBI of 14 while one sample in fall 2009 had a score of 16 (because the % dominance metric was less than 80%). B-IBI scores are often very stable in heavily urbanized watersheds because of the reduced benthic invertebrate diversity.
- Mean taxa (all invertebrates sampled) richness for all samples was 6.7 (range of 5 to 11) (see Figure C-5). Mean EPT taxa richness (stoneflies, mayflies, caddisflies) was 1.1 (range of 1 to 2). Both metrics indicate very poor stream condition.
- The benthic invertebrate community is stable through time with no clear trends in changing taxa presence or absence. The community is dominated by three taxa: the pollution-tolerant stonefly *Baetis tricaudatus*, a midge (*Ceratopogoninae*) closely related to blackflies, and Oligochaete worms. Together they accounted for over 95% of the individuals sampled in Quibble Creek, with *Baetis tricaudatus* being the most abundant (40% of all individuals sampled). All three are characteristic taxa in urban streams in Metro Vancouver.

Full taxonomic data and individual B-IBI scores by year are provided in the data tables at the end of this appendix (data tables C-1 and C-2). More information on Surrey's benthic invertebrate sampling program is available is available from City of Surrey, Drainage & Environment staff.

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[5] Lilley, P. and N. Page. 2011. 2010 City of Surrey Benthic Invertebrate Sampling Program: Methods and Results. Unpublished report for City of Surrey Engineering Department. 378 pp.

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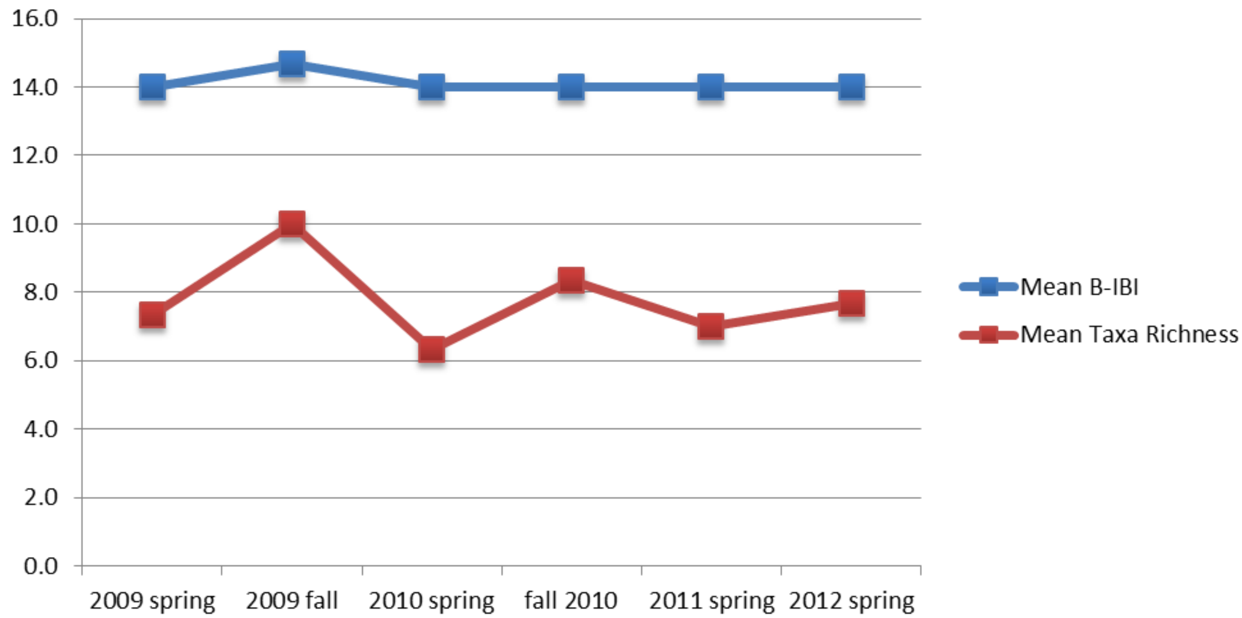

Figure C-5: Summary of benthic invertebrate community change in Quibble Creek (2009 to 2012) based on B-IBI and taxa richness values.

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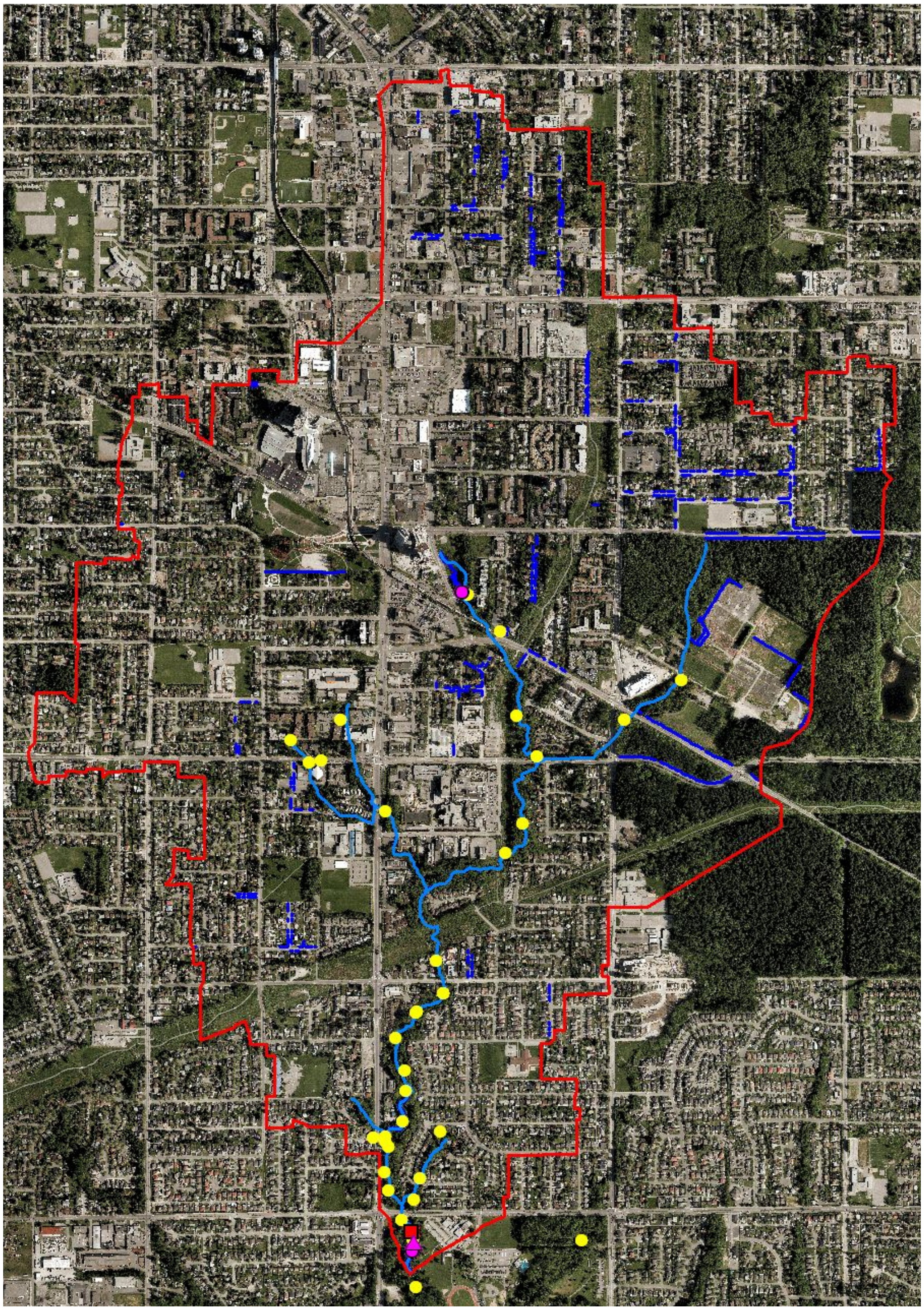

Figure C-6: Location of water quality survey points (yellow dots), sediment quality sample (purple triangle), temperature monitoring (purple dots), and benthic invertebrate monitoring site in Bear Creek Park (red square).

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Fish Community

Information on the fish community in Quibble Creek and its tributaries has not been comprehensively assessed in any one study. Kistritz (1995) described the results of a brief fish sampling survey using an electrofisher in the Quibble Creek mainstem and major tributaries. Only juvenile coho salmon were caught in the mainstem up to 100 Ave and lower section of King George Creek. He also noted the presence of "two to three dead salmon carcasses" in Quibble Creek below 88 Ave in late autumn 1994. This was considered a noteworthy observation and indicates that spawning populations were relatively small.

The City of Surrey's watercourse classification map summarizes fish presence information based on historical sampling and habitat suitability. It is presented in Figure C-7.

New Fish Sampling – Summer 2012 Minnow Trapping Survey. A brief trapping survey using minnow traps was undertaken in early July 2012 in headwater areas to confirm fish presence (see Figure C-8 for locations). Traps were baited with canned tuna and left for 20 to 24 hours before retrieval. Traps were set in groups of three in suitable habitat for juvenile coho salmon and cutthroat trout. Key results of the minnow trapping survey were:

- Three fish species were captured: juvenile coho salmon, juvenile cutthroat trout, and threespine stickleback. One western brook lamprey was also observed during the survey.
- Both coho salmon and cutthroat trout were captured in the lower section of the King George Creek as well as in the Quibble Creek mainstem upstream of the Fraser Highway. This confirms previous observations of coho salmon use in Quibble Creek (see City of Surrey watercourse classification and Kistritz, 1995).
- Recently emerged juvenile coho fry were also observed throughout the Quibble Creek mainstem in May 2012 but appeared to decline in abundance upstream of 96 Ave.
- No fish were captured in the East Tributary upstream of 140 Street despite suitable habitat.

New Fish Sampling – Fall 2012 Spawner Survey. A survey of adult spawning use was undertaken on November 15 and 23, 2012 to map the distribution of spawning chum and coho salmon. The mainstem and bottom end of significant tributaries were walked and spawning fish were recorded and mapped using a hand-held GPS. Key results were:

- A total of 659 spawning salmon were recorded during a 2-day survey in November 2012: 122 coho and 537 chum (Figures C-9 and C-10).
- All spawning was recorded in the Quibble Creek mainstem, except for minor coho (6 fish) and chum (9 fish) use in the lower 320 m of the King George Creek. Other tributary streams were either blocked by impassible culvert barriers or did not have suitable spawning habitats.
- Chum salmon spawning use was generally continuous between the confluence with Bear Creek to the Quibble Creek greenway bridge (hospital district pedestrian bridge).
- Coho salmon spawning use was more widely distributed and occurred in concentrated areas between the outlet in Bear Creek Park to upstream of Fraser Highway. Important spawning areas for coho salmon were (1) in the lower reach from the outlet to upstream of 88 Ave; (2) within and upstream of the main utility corridor (between 92 Ave and 94 Ave); and (3) from 94A Ave upstream to Laurel Drive.

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- Kistritz (1998) stated that the main spawning habitat was located from Laurel Drive downstream to the confluence with Bear Creek, but extended upstream to Fraser Highway. The 2012 assessment confirmed that observation but provided more detailed information on sections of higher spawning use.
- There are no historical spawning escapement records for Quibble Creek as it was not separated from the Serpentine River[6] by DFO escapement monitoring.

Riparian Wildlife

Riparian wildlife was not inventoried as part of the ISMP, other than anecdotal observations collected during field surveys. Wildlife has been assessed in the Green Timbers Urban Forest but not in the Quibble Creek corridor.

Tracks of raccoon and river otter were observed in several locations along the mainstem, and red-legged frog (a threatened species) was observed along the mainstem and tributary streams. More surveys are needed to better understand wildlife use in the Quibble Creek watershed.

[6] Hancock. M.J. and D.E. Marshall. 1985. Catalogue of salmon streams and spawning escapements of statistical area 29, New Westminster subdistrict. Canadian Data Repon of Fisheries and Aquatic Sci-ences 495.

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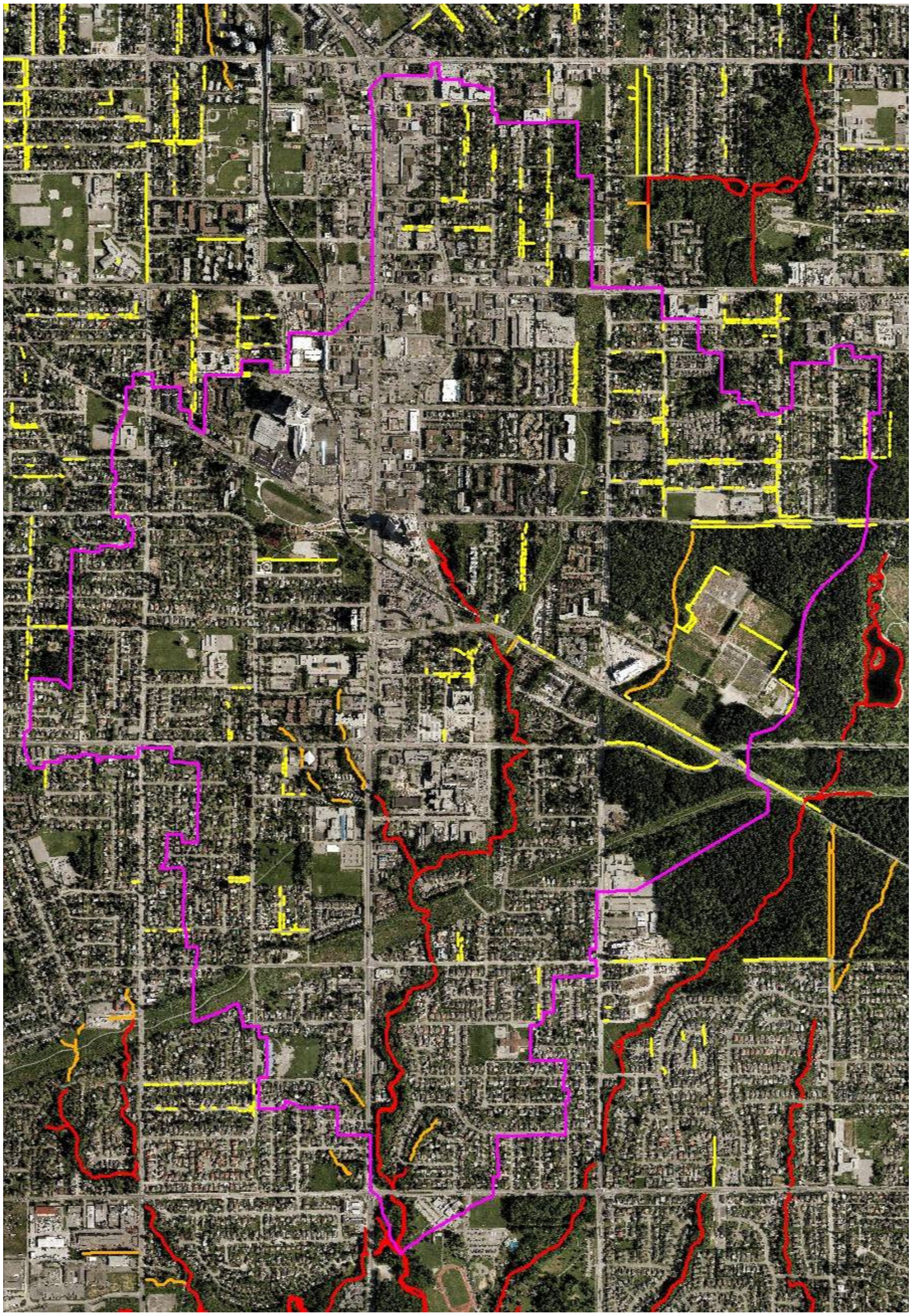

Figure C-7: City of Surrey's watercourse classification for the Quibble Creek watershed. Red coded watercourses are inhabited by fish.

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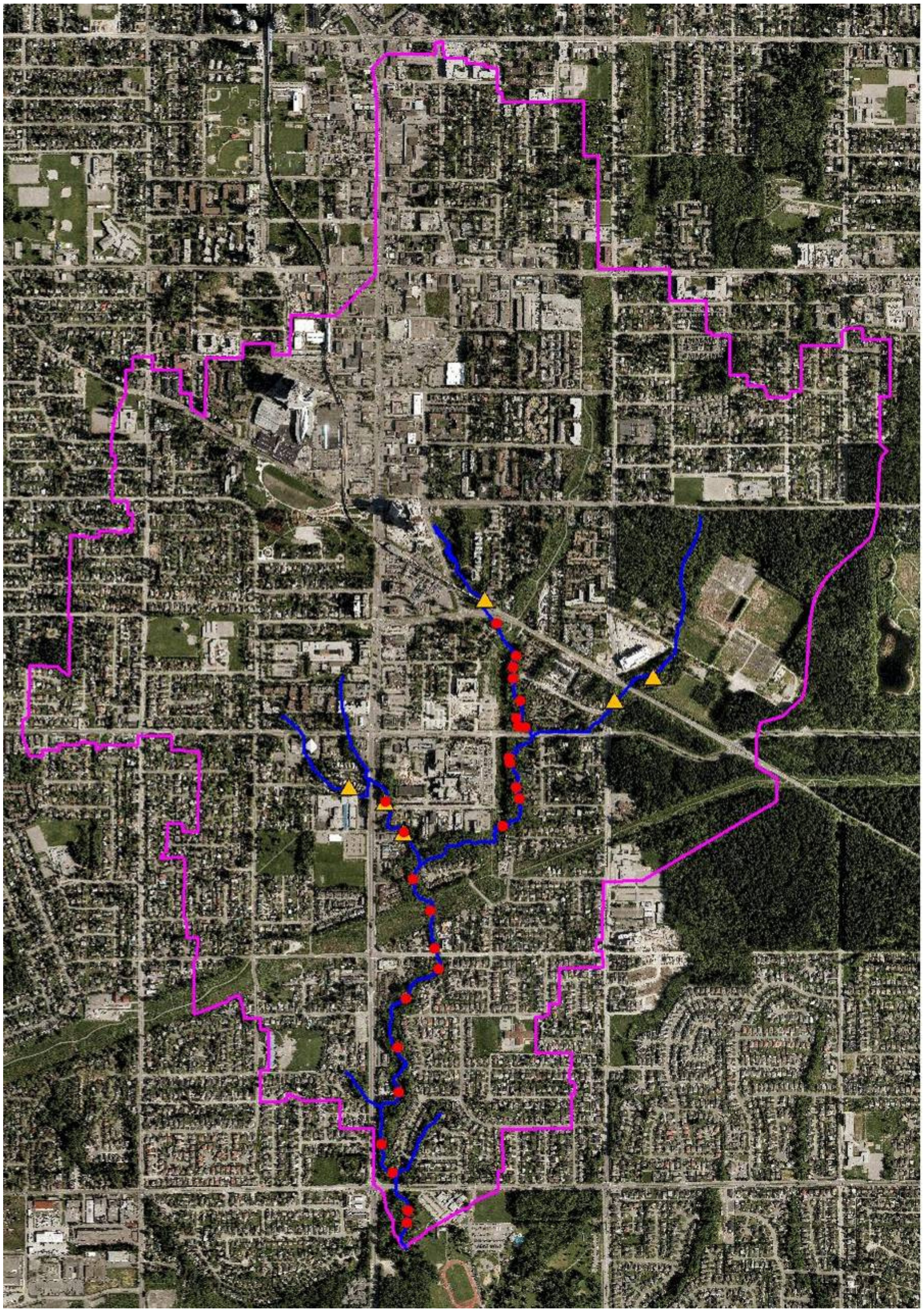

Figure C-8: July 2012 minnow trapping locations (orange triangles) and observations of juvenile coho salmon (red dots) during May 2012 field survey.

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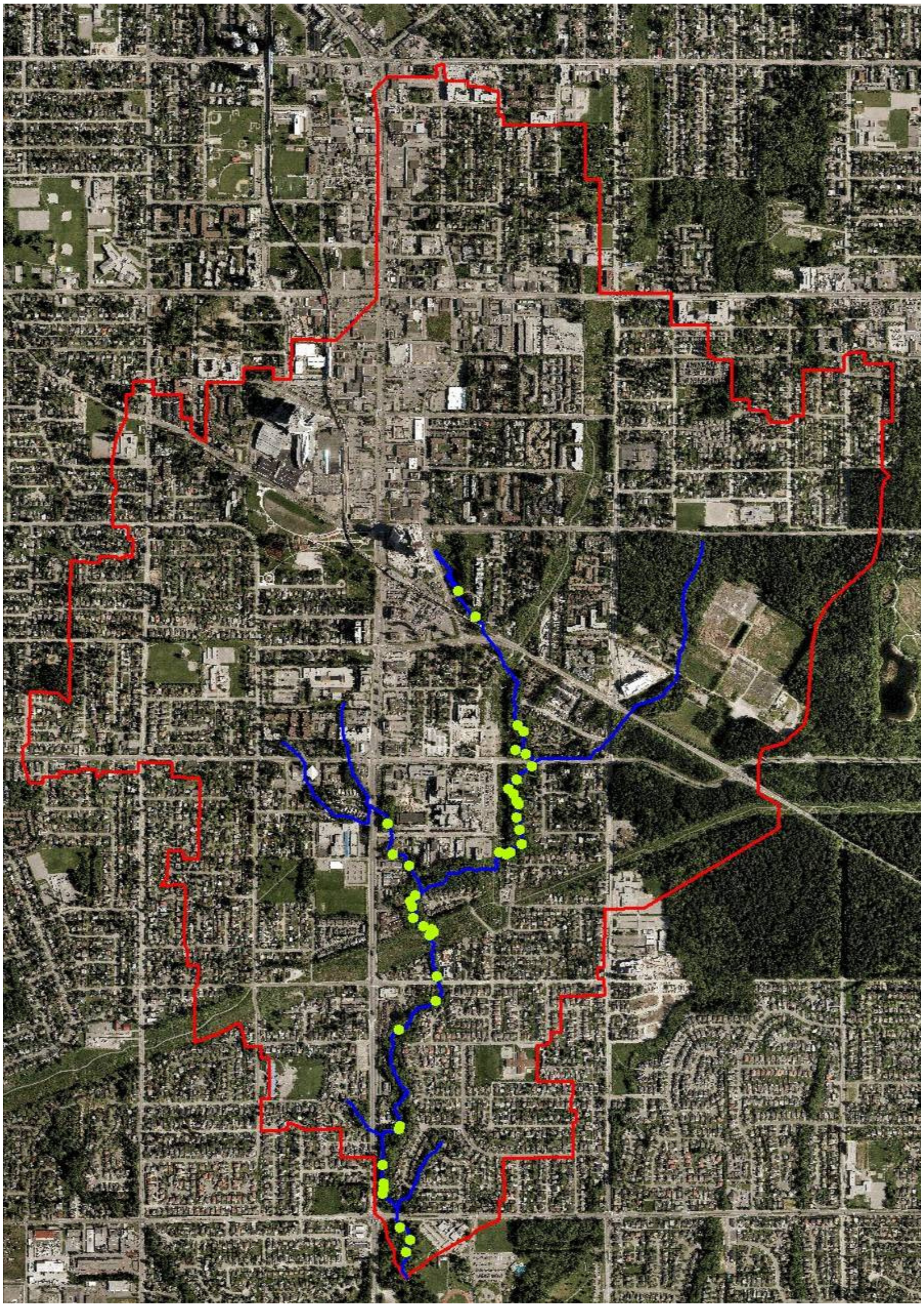

Figure C-9: Coho salmon spawning locations in November 2012 (122 fish in total).

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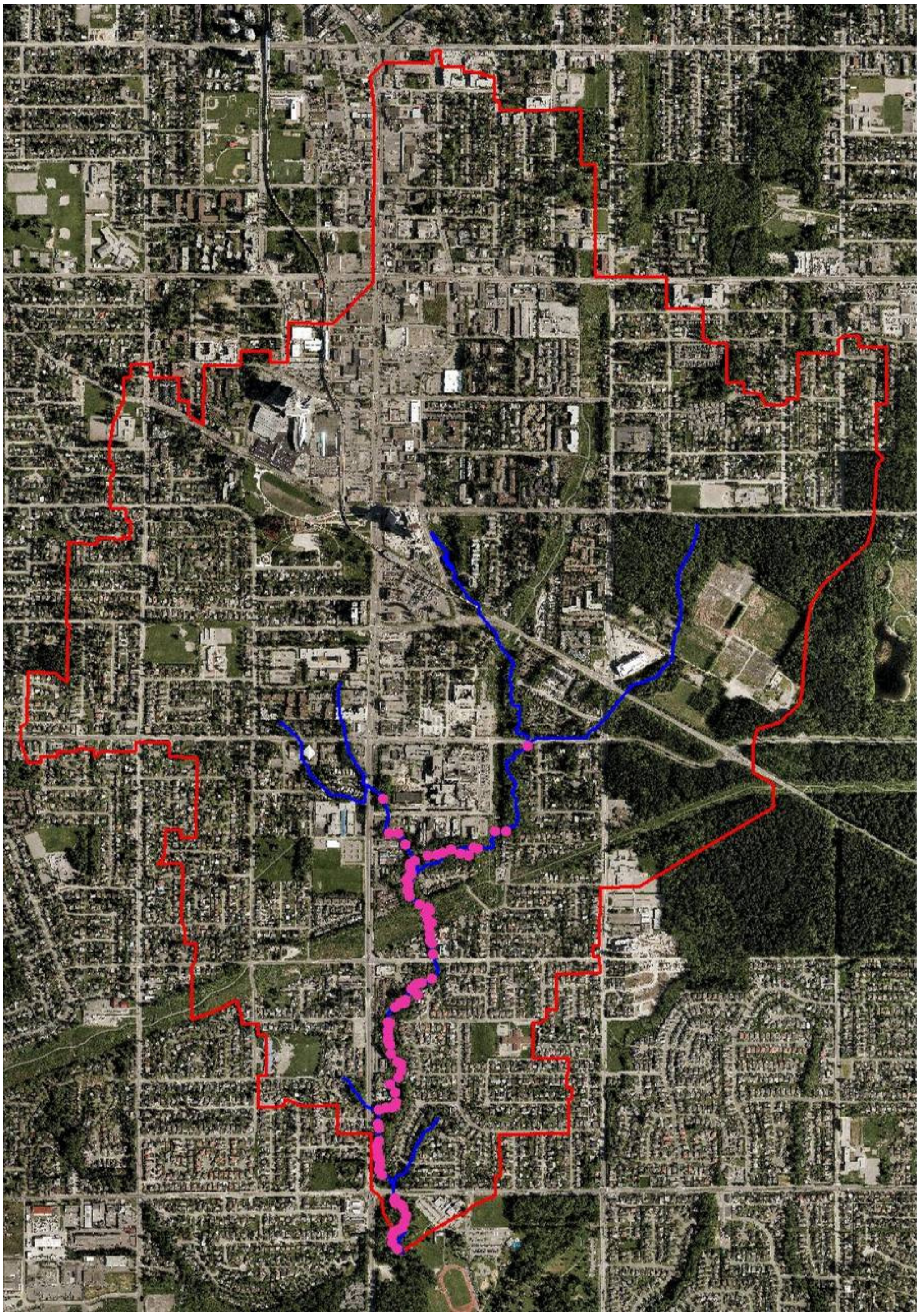

Figure C-10. Chum salmon spawning locations in November 2012 (537 fish in total).

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Figure C-11: Dead female chum salmon in Quibble Creek in Bear Creek Park (November 2012).

Figure C-12: Juvenile coho salmon and cutthroat trout in Quibble Creek (July 2012).

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Instream Fish Habitat

Fish habitat characteristics (channel dimensions, substrate, channel complexity, etc.) were assessed during field visits in May and June 2012. To understand the distribution of different habitat types, channel dimensions and substrate conditions were measured at 35 points at 100 to 150 m intervals along the mainstem and major tributary streams (see Figure C-13 for locations and Figure C-18 for representative photos). Bankfull width, wetted width, substrate composition (visual estimate of % boulder, cobble, large gravel, small gravel, silt/sand), and substrate embeddedness were recorded. These measurements provide quantitative information on channel conditions as well as providing data that can be monitored over time.

In addition, pieces of large wood (greater than 10 cm in diameter and 2 m long; often called "large woody debris: LWD") and pools >40 cm deep were mapped as indicators of fish habitat value. Large wood and deep pools are important for sustaining salmon and trout populations, particularly juvenile coho salmon and cutthroat. Large wood is an important structural feature in small coastal streams which is reduced or eliminated by urbanization.

Channel Dimensions. Mean bankfull width in the Quibble Creek mainstem in May 2012 was 6.0 m (range of 3.4 to 9.2 m) and wetted width was 4.5 m (range of 2.4 to 8.5 m). The overall wetted area in May-June 2012 for Quibble Creek and permanently flowing tributaries was 2.1 ha. Figure C-16 presents a graphical summary of changing channel dimensions in the Quibble Creek mainstem.

Substrate. Instream substrate is predominantly cobble and gravel with lesser amounts of boulder and fine sediment (sand and silt) (see Figure C-17). Mean substrate was 11% boulder, 31% cobble, 30% large gravel, 18% small gravel, and 10% fines. Percent embeddedness, a measure of the sedimentation of substrate, was 23% (meaning about ¼ of a typical piece of cobble is embedded in the stream bed). The channel steepens and the amount of boulder substrate increases around 90 Ave.

Large Wood. Large instream wood is widely distributed in the Quibble Creek mainstem and tributary streams but rarely abundant compared to undisturbed streams (see example photos in Figure C-19). A total of 210 pieces were recorded with an average length of 8.5 m, diameter of 35 cm and volume of 0.91 m^3. Wood pieces were not differentiated by species or age/condition.

The density of large instream wood was 3.2 pieces per 100 m of stream channel. Natural streams typically have been 10 and 20 pieces per 100 m and wood volume is often much higher. Overall, the survey indicates that Quibble Creek is relatively barren of large instream wood.

Deep pools. Fifty-two pools deeper than 40 cm deep were measured in May 2012. Most were found in the Quibble Creek mainstem and King George Creek. Mean depth was 59 cm (range of 40 to 135 cm). There was no clear pattern or concentration of pool development related to channel dimensions, gradient, or other factors. Deep pools were generated by a range of processes including lateral erosion against stable banks, scour around large wood or other features, or the presence of culverts or other anthropogenic features.

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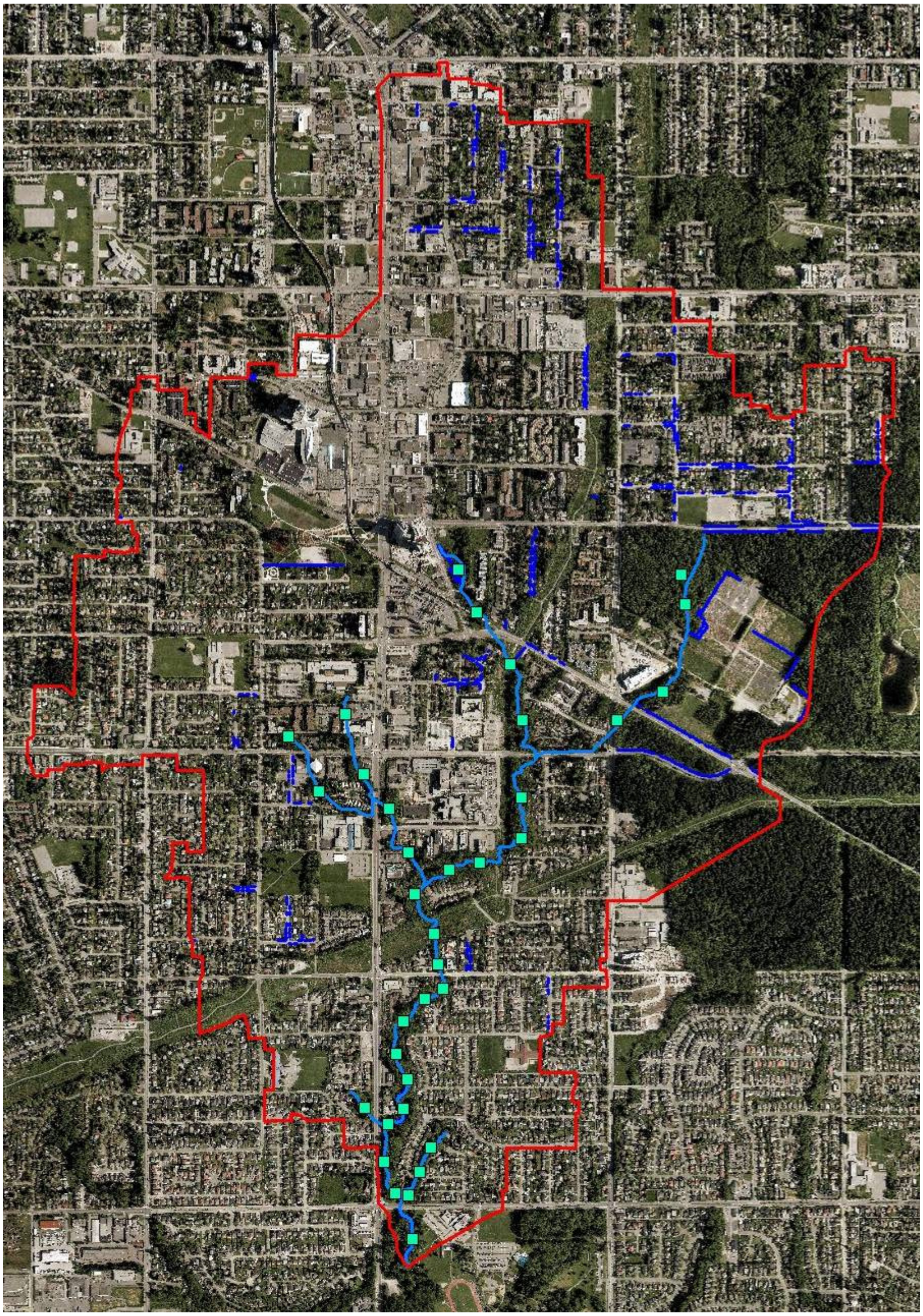

Figure C-13: Location of channel and habitat condition measurement points.

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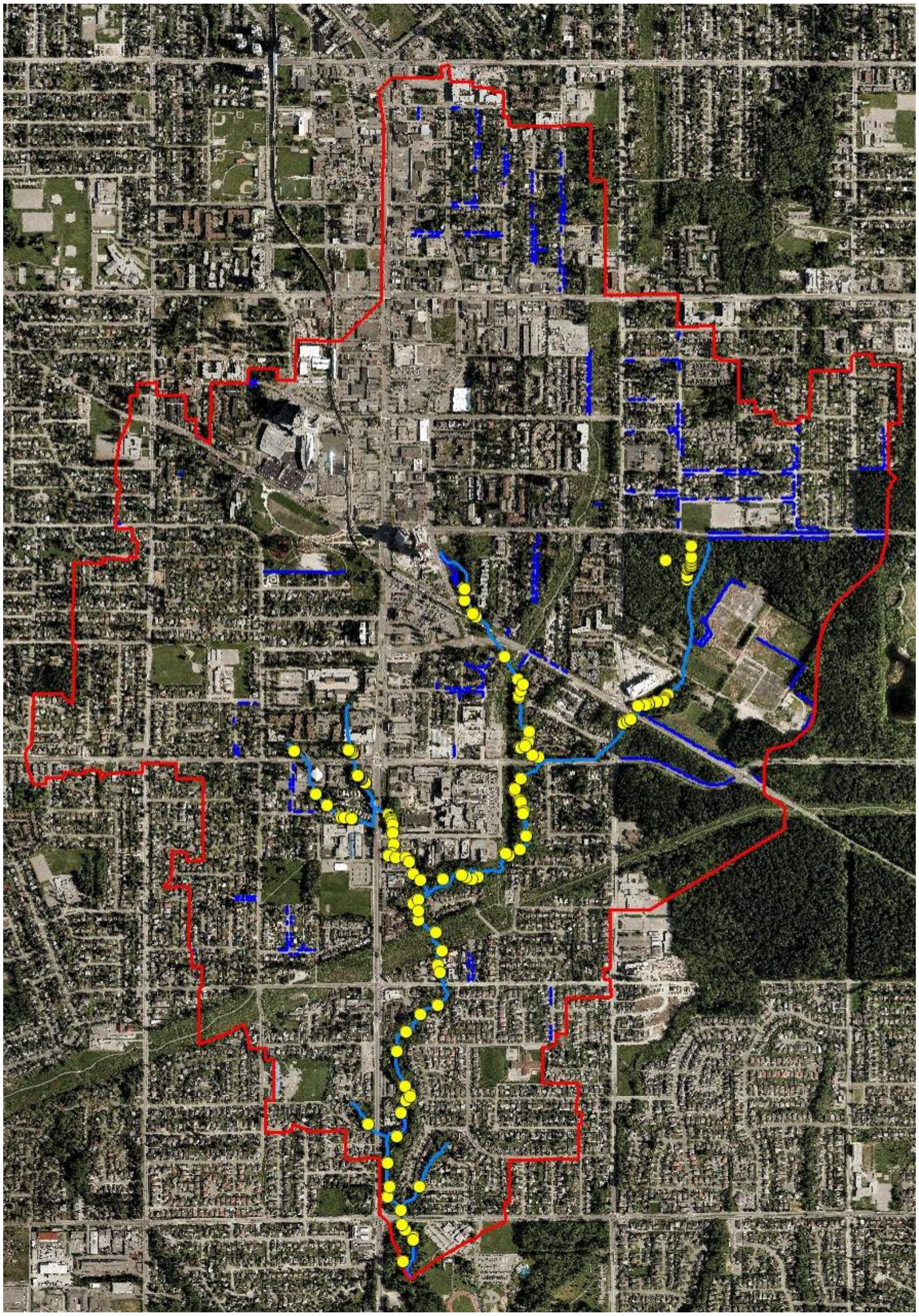

Figure C-14: Distribution of instream large wood (larger than 2 m long and 10 cm in diameter) in Quibble Creek and tributary streams measured in May 2012.

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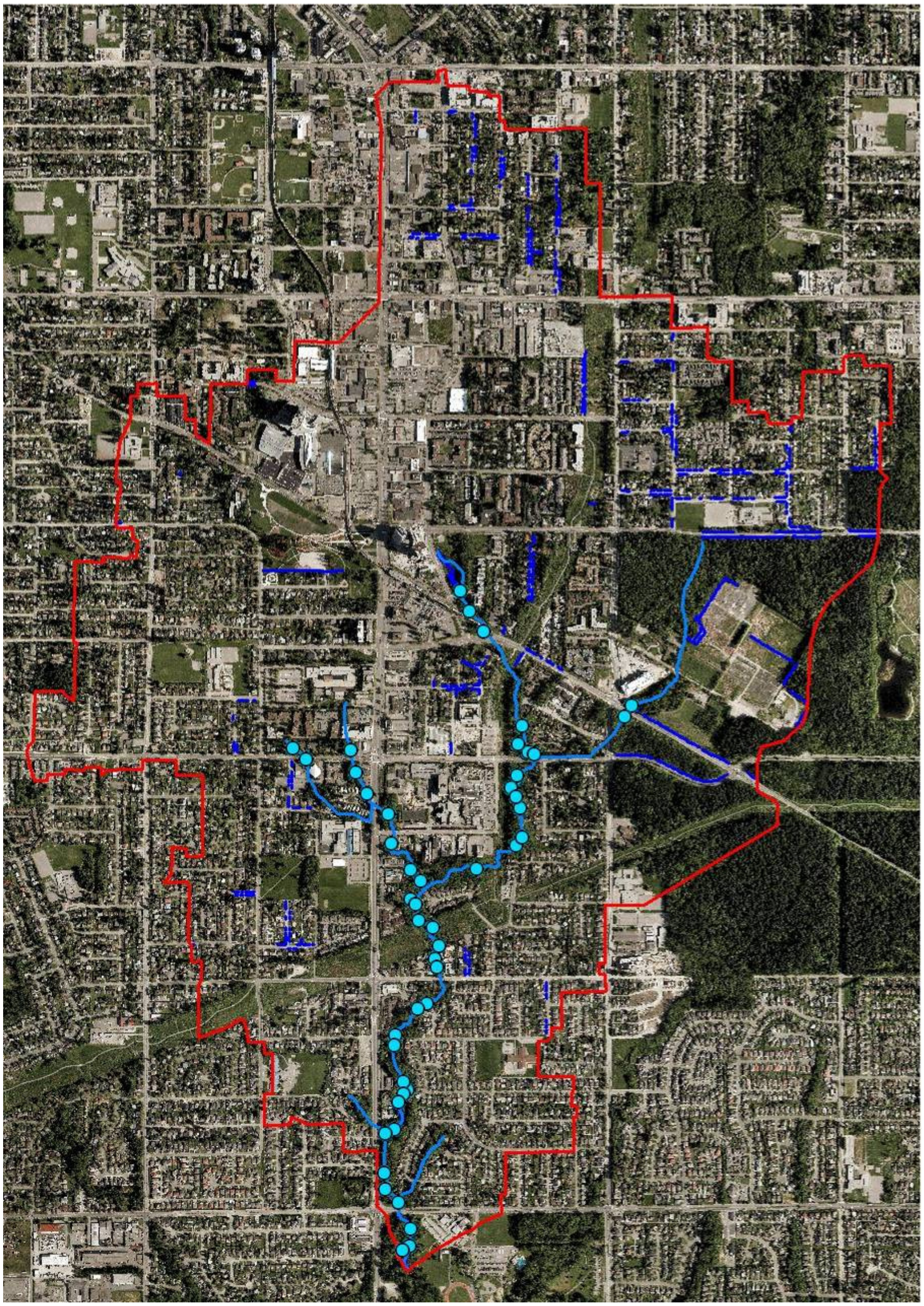

Figure C-15: Distribution of deep pools (>40 cm deep) in Quibble Creek and tributary streams measured in May 2012.

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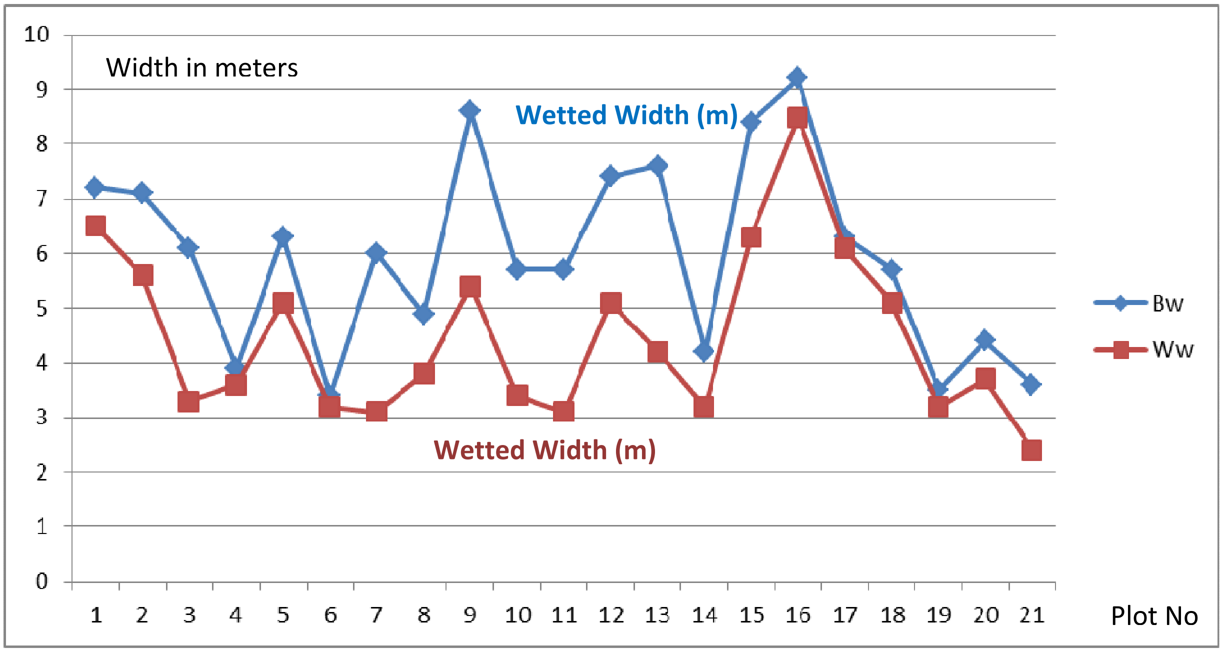

Figure C-16: Changes bankfull width and wetted width in Quibble Creek mainstem during May 2012 field survey (100 to 150 m intervals starting at confluence with Bear Creek).

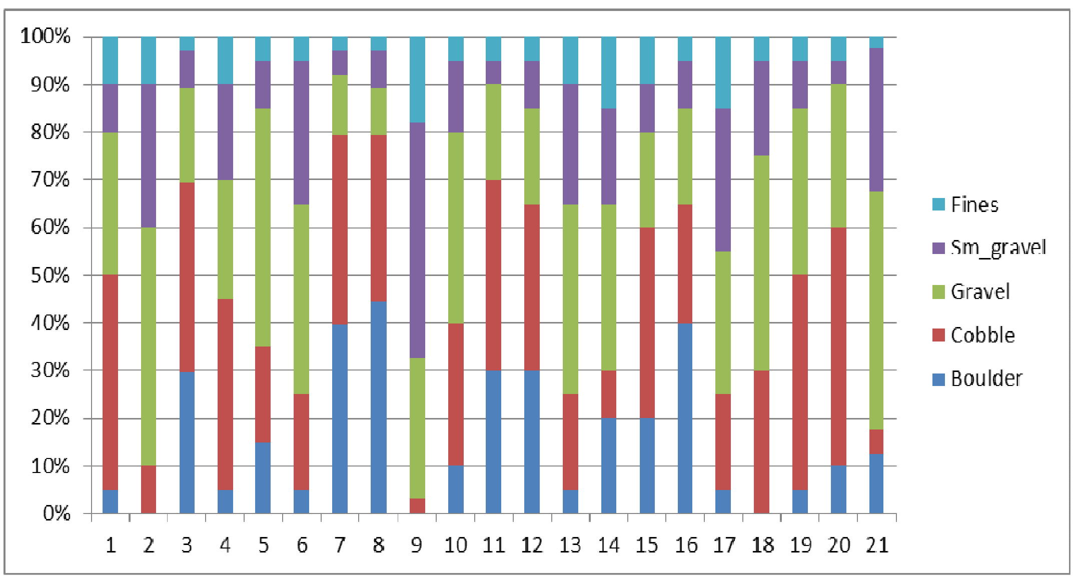

Figure C-17: Changes in substrate composition in Quibble Creek mainstem.

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a b c d

Figure C-18: Examples of instream habitat conditions in Quibble Creek.

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Figure C-19: Examples of instream large wood that is contributing to channel complexity or pool forming processing in Quibble Creek.

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Barriers to Fish Passage

Fish use in Quibble Creek is limited by six culvert barriers, mainly at the outlet of tributary streams. Figure C-20 presents locations of significant fish passage barriers and Figure C-21 provides example photos. Kistritz (1998) also identified barriers to fish passage throughout the Bear Creek watershed including Quibble Creek; none have been addressed in the past 15 years.

Key fish passage barriers or fish passage issues include (from downstream to upstream starting with the Quibble Creek mainstem):

- The upper limit of fish movement in Quibble Creek is the culvert outlet 65 m downstream of 100 Ave (see Photo A in Figure C-21). This is also the upstream extent of open stream channels; headwater channels were lost during the intense urbanization phase.
- An impassable culvert [need to confirm length and diameter] at the outlet of Ursus Creek, the small tributary stream entering from the east side of Quibble Creek about 10 m upstream of 88 Ave, precludes upstream fish movement. Ursus Creek does not support resident cutthroat trout.
- There is an impassable culvert [need to confirm length and diameter] at the outlet of “Bryan Creek” the small tributary stream entering from the west side of Quibble Creek upstream of 88 Ave. The stream is open through Bryan Park but does not likely provide year-round flow. It does not support resident cutthroat trout.
- A combination of culverts at King George Highway prevent fish access into the headwaters of two branches of King Geoge and Queen Elizabeth creeks. Resident cutthroat trout are not present in either headwater channel.
- A series of culverts totalling approximately 330 m prevent fish from accessing Laurel Creek the headwater stream in Green Timbers Urban Forest (see Photo D in Figure C-21 showing outlet).
- An additional culvert on Laurel Creek is present under Fraser Highway.

Additional fish passage issues include:

- Several debris jams composed of composed of large and small wood debris and urban garbage were observed upstream of Fraser Highway, and in the dense willow thicket upstream of the Quibble Greenway bridge crossing (in the hospital district). None were considered barriers to fish passage during storm flows and are typically temporary in nature.
- The trail culvert at 94A Ave is likely a barrier to the upstream movement of juvenile fish during low summer flows but is not considered a barrier to adult fish (see Photo B in Figure C-21).
- The culvert outlet control structure downstream of Fraser Highway may reduce upstream fish movement under some flow conditions (see Photo E in Figure C-21).

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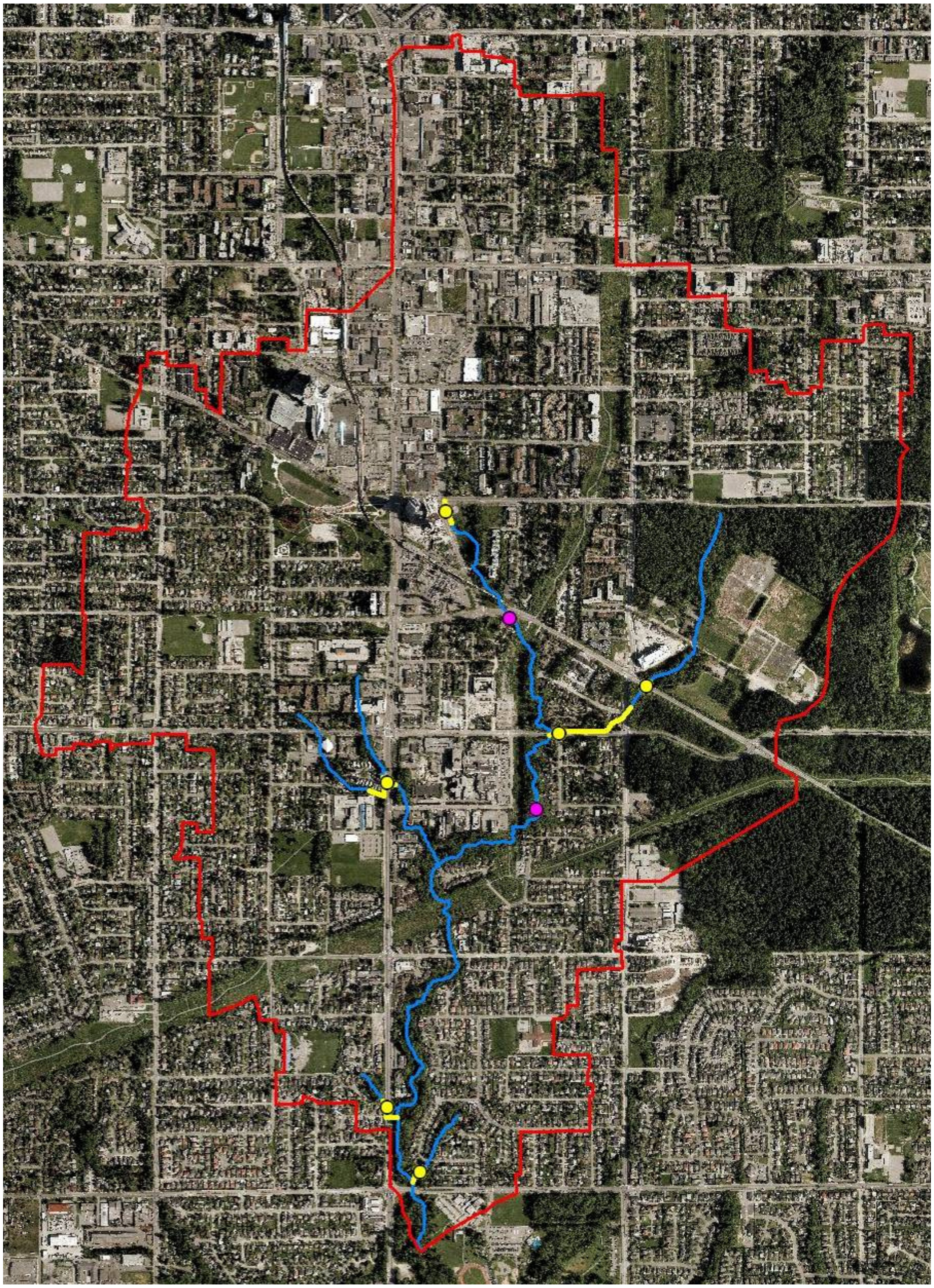

Figure C-20: Important fish passage barriers in the Quibble Creek watershed. Barriers are shown with yellow lines and dots and other passage concerns are shown with violet dots.

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Figure C-21: Fish passage issues in Quibble Creek: (a) is the upper extent of Quibble Creek mainstem near 100 Ave; (b) culvert barrier to juvenile fish under low summer flows at 94A Ave; (c) passable culvert under Fraser Highway (upstream end with baffles); (d) culvert outlet control downstream of Fraser Highway may restrict fish movement under lower flows.

Previous Fish Habitat Enhancement Projects and Compensation

Some previous fish habitat enhancement or compensation activities have been undertaken in the Quibble Creek watershed. They include:

- 100 tons of boulders were added to Quibble Creek in 1981 within Bear Creek Park to enhance fish habitat (FISS, 2012); many are still present (Photo C in Figure C-22);

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- Small instream rock weirs were recorded upstream from 88 Ave. Their history is not known.
- Large wood was added to a section of the Quibble Creek mainstem within the utility corridor (see Photo B in Figure C-22). They appear to be effective at creating more complex channel structure.
- An off-channel pond was constructed within the Quibble Creek riparian corridor upstream of 96 Ave (west side) (see Photo A in Figure C-22). No information on the history or performance of this feature was reviewed.
- The large stormwater pond and bypass channel downstream of 100 Ave likely provides some fish habitat value (see Photo D in Figure C-22). Its function as a fish habitat feature is secondary to its value for water quality improvement (sediment removal).
- There are other smaller riparian enhancement projects that are associated with development activities.

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Figure C-22: Previous fish habitat enhancement projects in Quibble Creek: (a) off-channel pool upstream of 96 Ave; (b) instream wood in utility corridor; (c) older boulders and wood in Bear Creek Park; and (d) stormwater pond downstream of 100 Ave provides some fish habitat value.

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Proposed Environmental Enhancement and Restoration Activities

Restoration and enhancement opportunities were identified that focus on four components:

1. Landscape-level connections including forest protection or restoration that support the City's green infrastructure network as well as watershed-scale functions;
2. Riparian restoration and management that focuses on increasing the amount and ecological function of riparian forest;
3. Instream and off-channel habitat restoration to enhance fish populations; and
4. Fish passage improvements to restore access to habitat.

Priority actions are described below and locations are shown in Figures C-24 and C-25. They are also summarized in Table 7-6.

Watershed and Landscape-scale Actions

- The Green Infrastructure Network analysis identified Green Timbers Urban Forest and Bear Creek Park as important large natural areas (hubs) in north central Surrey with connections through King Creek and other corridors (Figure C-23). Quibble Creek was considered a local (secondary) corridor because it is longer and more discontinuous than King Creek. However, the Quibble Creek corridor has substantial connectivity values that can be enhanced through land acquisition, forest planting, and other actions.
- There are limited opportunities to increase non-riparian forest cover because of the existing high level of development, limited park space, and vegetation management constraints on the utility corridors. The integrity of the existing forested riparian corridor reduces opportunity for substantial gains through reforestation.
- Areas outside of stream or utility corridors are also important for improving landscape-level connectivity. For example remnant tree patches between Green Timbers and the Quibble Creek corridor are important stepping-stone habitats for birds and other mobile wildlife species.
- The eastern side of the watershed between 92 Ave and Fraser Highway was identified as an important area for improving landscape-level connectivity. Tree retention during redevelopment, active tree planting or garden naturalization, street closure or narrowing and park acquisition (as small as single lots) should be emphasized in these areas. Figure C-24 shows the general boundary of this area (green polygon) and identifies several small forest patches that should be protected during redevelopment. More direction on biodiversity management is presented in the City's developing Biodiversity Conservation Strategy.
- Enhanced park acquisition should be considered for protecting remaining forested areas in the Quibble Creek watershed with emphasis on the eastern side.
- Four park areas totalling 2.2 ha were identified for reforestation in non-riparian areas, both as a means to increase ecological value and to restore hydrological functions provided by tree vegetation and forest soils over the long term.

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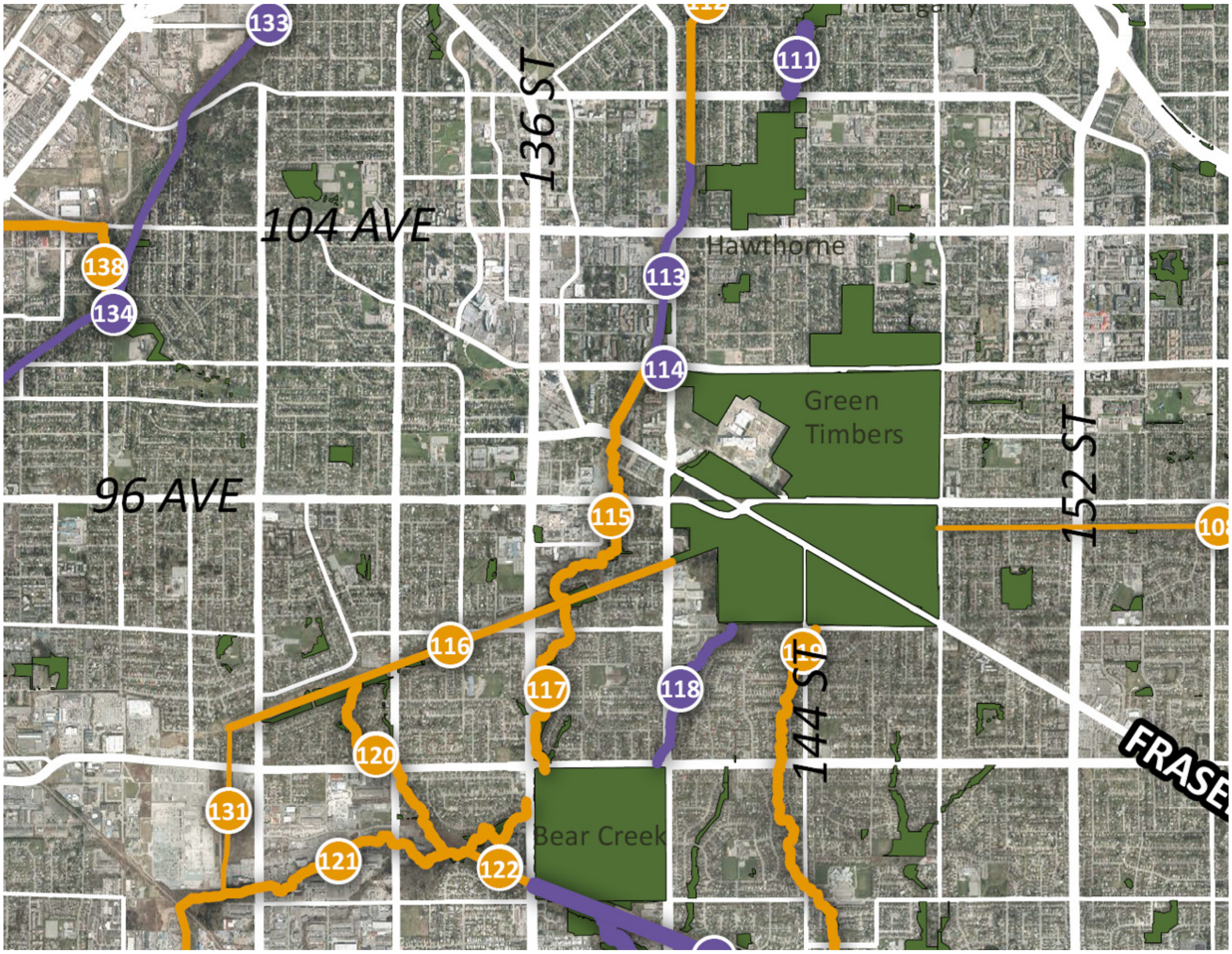

Figure C-23. Landscape scale natural areas and important corridors in or near the Quibble Creek watershed. Purple lines indicate regional corridors and orange lines indicate local corridors (from City of Surrey Biodiversity Strategy, May 2013 draft map).

Riparian Corridor Actions

- There are limited opportunities to increase riparian forest cover along Quibble Creek mainly because the existing corridor is well-developed and surrounded by existing residential or institutional land use. Opportunities for additional riparian protection may occur during redevelopment but are likely to be relatively modest.
- Six sites totalling 1.5 ha were identified for reforestration within the Quibble Creek riparian corridor. The largest site (1.1 ha) is located in Bear Creek Park. Riparian reforestation costs are estimated to be $50,000 to $120,000 per hectare.

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- Additional sites (not shown on map) were identified for invasive species management including control of Himalayan blackberry, English ivy, yellow lamium, and Japanese knotweed.
- Localized areas of recreation-related disturbance should also be addressed through trail relocation or closure, fencing, signs, and other strategies. None were considered to have a major effect on stream health.

Instream and Floodplain Actions

- The reduced density of large wood and deep pools compared to less disturbed streams suggests that instream habitat restoration could increase fish habitat value.
- Seven instream habitat restoration sites (stream segments) totalling 835 m of channel were identified based on existing channel conditions and access to the stream channel for restoration. Specific sites were identified based on channel conditions and access. Suitable techniques include large wood or wood clusters where flood risk is minimal, and boulder groups where there is a risk to infrastructure if large wood is used.
- The target for instream enhancement should be to increase the amount of instream wood from 3.2 pieces per 100 m to 5 pieces per 100 m by 2025. This would require the addition of about 120 pieces of wood.
- There are also limited opportunities for the creation of off-channel (floodplain) habitats such as ponds, channels, and wetlands because of shallow ravine topography (3 potential sites were identified totalling 0.26 ha).

Fish Passage Improvements

Most of the fish passage issues are difficult to address because they will require substantial infrastructure change with relatively little benefit. Recommended actions include:

- Removal of the culvert at the mouth of Ursus Creek to restore fish access to the lower 95 m of this small stream.
- Replacement of the culvert under 94A Ave (greenway trail) with a clear-span bridge. This culvert does not restrict adult fish migration but likely limits the upstream movement of juvenile fish under low summer flows.
- Assessment of opportunities to address culvert barriers at King George Creek and Laurel Creek tributaries over the long term as part of infrastructure renewal.

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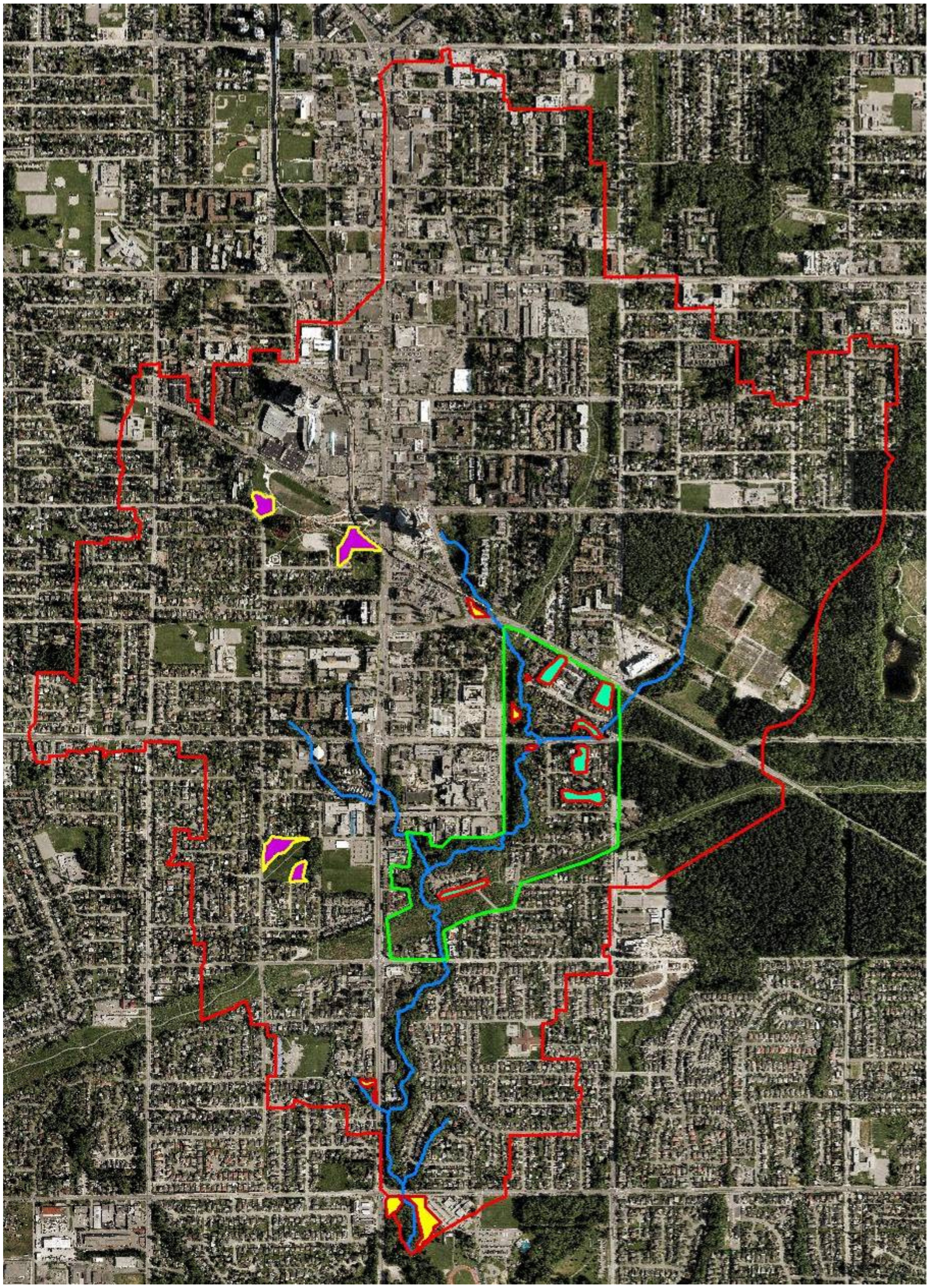

Figure C-24. Location of propose riparian enhancement (yellow), watershed forest enhancement (violet), and forest protection areas (green). A broad landscape unit on the east side of the watershed that is important for landscape-level connectivity between Green Timbers and the Quibble Creek riparian corridor is also shown.

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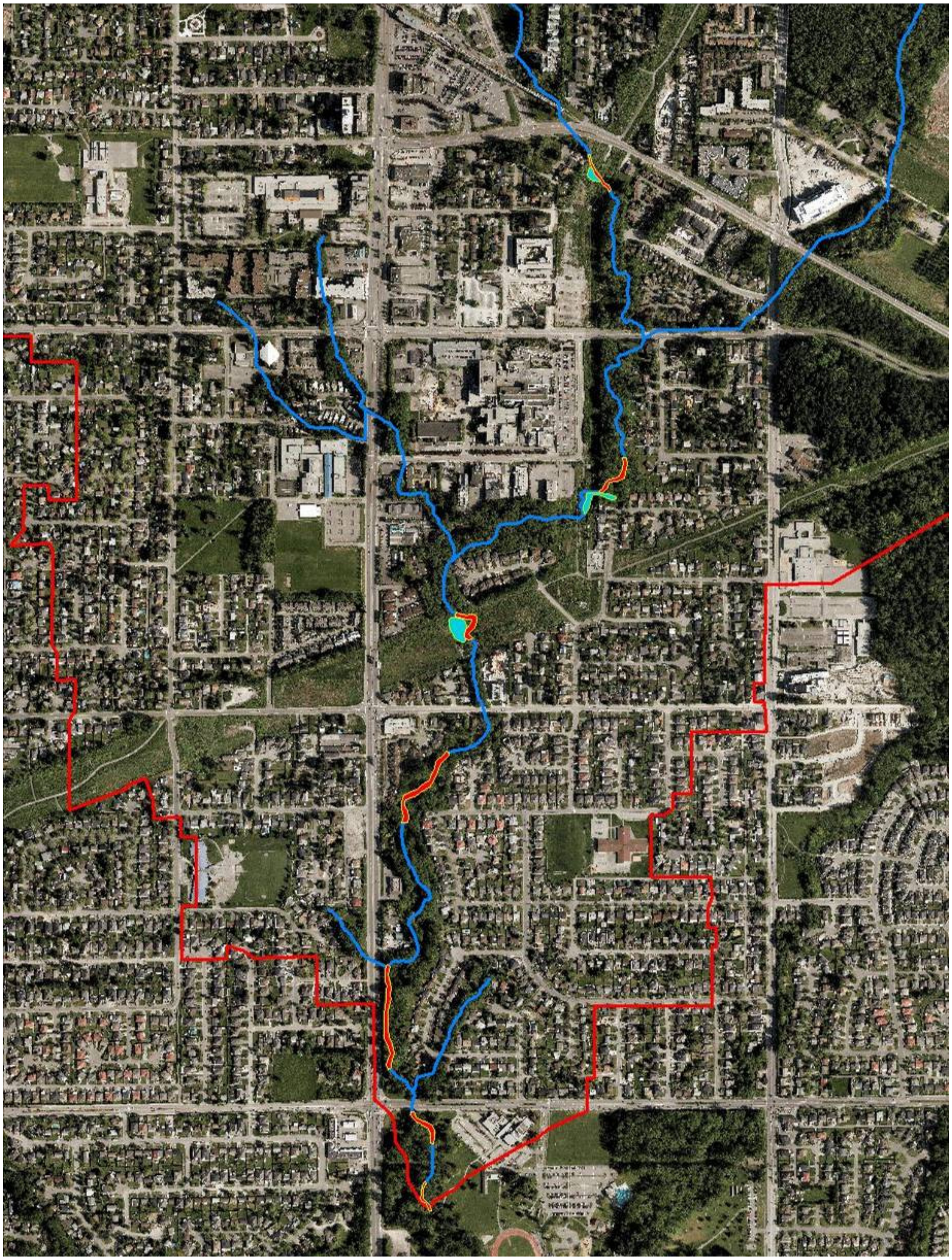

Figure C-25: Suggested instream (red segments) and off-channel (blue polygons) habitat restoration and enhancement sites in Quibble Creek watershed.

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Appendix C-1 Data Table. Benthic taxa sampled in Quibble Creek from 2009 to 2012. Note, dominant taxa are shown in bold.

Taxon	2009 Fall	2009 Spring	2010 Fall	2010 Spring	2011 Spring	2012 Spring
Acari			1			
Amphipoda		8	1	1	8	
Baetis bicaudatus			6			
Baetis tricaudatus	**577**	**194**	**156**	**1142**	**163**	**300**
Caecidotea	51	13	2	1	19	8
Ceratopogoninae		1		2		
Chironomidae	**134**	**588**	**67**	**43**	**257**	**289**
Clinocera						1
Crangonyx	29		1		1	3
Dicosmoecus gilvipes		1				
Dytiscidae		2		1	1	1
Erpobdellidae			1			
Ferrissia	42		3		2	
Glossiphoniidae			1			
Mooreobdella	7					1
Nematoda		3		2	9	
Neoplasta		2	1			4
Oligochaeta	**115**	**413**	**55**	**72**	**795**	**649**
Parapsyche almota	2					
Physa	3		1			
Piscicola	3					
Piscicolidae	1					
Planorbidae	3			1	1	
Polycelis coronata				1		
Promenetus		1				
Rhyacophila blarina			1			
Sphaeriidae	1		3	3		2
Tipula	3					
Turbellaria	10		2			1
Total Organisms	**981**	**1226**	**302**	**1269**	**1256**	**1259**

Appendix C-2 Data Table. B-IBI metric values for benthic invertebrate samples from Quibble Creek from 2009 to2012.

SITE NAME	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble	Quibble
SITE ID	BE2-1	BE2-2	BE2-3	BE2-1	BE2-2	BE2-3	BE2-1	BE2-2	BE2-3	BE2-1	BE2-2	BE2-3	BE2-1	BE2-2	BE2-3	QU1-1	QU1-2	QU1-3	QU1-1	QU1-2	QU1-3
	2009	2009	2009	2009	2009	2009	2010	2010	2010	2010	2010	2010	2010	2010	2010	2011	2011	2011	2012	2012	2012
	spring	spring	spring	fall	fall	fall	spring	spring	spring	spring	spring	spring	fall	fall	fall	spring	spring	spring	spring	spring	spring
Sample date	15/05/09	15/05/09	15/05/09	03/11/09	03/11/09	03/11/09	06/05/10	06/05/10	06/05/10	06/05/10	06/05/10	06/05/10	03/11/10	03/11/10	03/11/10	04/05/11	04/05/11	04/05/11	02/05/12	02/05/12	02/05/12
Proportion of sample used	47%	30%	100%	100%	100%	77%	40%	41%	70%	40%	41%	70%	100%	100%	100%	32%	27%	50%	17%	50%	18%
TOTAL	400	409	417	358	201	422	425	405	439	425	405	439	144	57	101	429	429	400	403	426	430
METRIC VALUES																					
Taxa richness	8	6	8	11	8	11	6	5	8	6	5	8	8	9	8	6	8	7	8	8	7
E richness	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1
P richness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T richness	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	1	1	2	1	1	2	1	1	1	1	1	1	1	3	2	1	1	1	1	1	1
INTOLERANT taxa richness	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Clinger richness	0	0	0	0	0	1	0	0	0	0	0	0	0	2	1	0	1	0	0	1	0
LL richness	2	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1	0
% tolerant	1.75	0.73	1.44	0.15	0.07	0.07	0.24	0.25	0.23	0.24	0.25	0.23	2.08	1.75	1.98	0.23	1.63	3.75	0.99	0.94	0.23
% predator	0.25	0.49	0.48	0.03	0.03	0.02	0.00	0.25	0.46	0.00	0.25	0.46	1.39	3.51	2.97	0.00	0.23	0.00	0.50	0.94	0.47
% dominance (3)	96.50	96.82	97.12	84.80	73.60	81.00	99.06	99.51	98.63	99.06	99.51	98.63	95.83	84.21	84.16	99.07	97.20	89.75	91.32	92.96	93.26
METRIC SCORES																					
Taxa richness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
E richness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P richness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T richness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
INTOLERANT taxa richness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Clinger richness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
LL richness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
% tolerant	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
% predator	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
% dominance (3)	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SAMPLE SCORE	**14**	**14**	**14**	**14**	**16**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**

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Appendix D

Hydrologic and Hydraulic Model

Appendix D – Hydrologic and Hydraulic Modelling

Contents

Figures (At End of Section)

Tables

Appendix D – Hydrologic and Hydraulic Modelling

D Hydrologic and Hydraulic Modelling

D.1 Introduction

This Appendix outlines the development of the detailed hydrologic and hydraulic model of the Quibble Creek Drainage Basin. The section includes:

- description of the detailed hydrologic and hydraulic model development using the City's GIS data base
- calibration and verification of the hydrologic model to ensure accurate predictions of watershed rainfall-runoff response
- description of the detailed hydrologic and hydraulic future mitigated model

The completed hydrologic/hydraulic models were used to assess the drainage system under different design event conditions and continuous historical rainfall periods. The results of these analyses are presented in Appendix E.

D.2 Rainfall and Flow Monitoring Data Collection

Rainfall Data

The rainfall data for model calibration was collected from the Kwantlen Park rain gauge and the Surrey Municipal Hall rain gauge. See Figure D-1 for the rainfall and flow monitoring station locations.

The design storms used in the analysis were those contained in the City of Surrey *Design Criteria Manual*(2004) and are described in section D.6.

Flow Monitoring

The flow monitoring data was sourced from a gauge installed on 88th Avenue. The flow monitoring station has been in operation and continuously recording data since 1996.

Water level at the station is measured using a compressed nitrogen bubbler system and recorded in a Data Logger. The data is transmitted via landline to the FlowWorks server which can be accessed by logging into www.flowworks.com. The water levels are converted to flow using the stage-discharge relationship shown on Figure D-2.

D.3 Percentage Impervious

The existing land use total impervious percentages used in the model were based on the City's *Design Criteria Manual, 2004* values and are repeated in

Appendix D – Hydrologic and Hydraulic Modelling

Table D-1 below. In addition to the City's values, road catchments were assigned total percent impervious value of 70%.

Appendix D – Hydrologic and Hydraulic Modelling

Table D-1: Land Use Impervious Percentages (Prior to Calibration)

Land Use	Total Existing Impervious Percentage	Total Future Impervious Percentage
One Acre Residential Zone	25	35
Single Family Residential Zone	65	75
Single Family Residential Secondary Suite Zone	65	75
Single Family Residential (12) Zone	80	80
Duplex Residential Zone	65	75
Multiple Residential 15, 30 &45 Zone	80	90
Local Commercial Zone	90	90
Community Commercial Zone	90	90
Tourist Accommodation Zone	65	75
Child Care Zone	80	90
Assembly Hall 1 & 2 Zones	80	90
Comprehensive Development Zone	Varies	90
ROW	70	80

Appendix D – Hydrologic and Hydraulic Modelling

During the calibration of the model, the percentage impervious of catchments with low impervious coverage located on sand and silt/clay were adjusted to replicate the observed flow rates at the 88th Avenue flow station. The changes made to the impervious coverage for each soil type are outlined below:

- Sand: Catchments with an overall percentage imperviousness of less than or equal to 65% had their overall imperviousness coverage reduced to 10%. This reduction in percentage imperviousness reflects the fact that the majority of residential homes in the Quibble/Bear Creek watershed have disconnected roof leaders. Ref. 1998, Master Drainage Plan, Kerr Wood Leidal.
- Silt and Clay: Catchments with an overall percentage imperviousness less than or equal to 65% had their overall percentage imperviousness reduced by 50%.
- Till: No changes were made to the catchments original percentage imperviousness.

For the future land use, total impervious percentages of most residential zones were increased by 10% due to tendency for redevelopment to encompass larger housing footprints (See section D.3.1). Total impervious percentages were not increased for commercial and industrial land use zones that had an existing impervious percentage of 90% as there is limited area to increase the impervious percentage of these lots.

For the existing land use model, the calibrated existing total impervious percentages were applied to the land uses. The existing total impervious percentages were then adjusted on a large number of residential lots to take account for undeveloped/underdeveloped lots. This check was carried out by comparing an orthophoto of the area with the assigned existing total impervious percentage.
The 656 ha watershed has an existing effective percentage impervious area (EIA) of 47%. The EIA is expected to increase to 64% once the catchment is built-out to the OCP. Figure D-3 and Figure D-4 show the distribution of effective impervious area in the watershed based on existing and future land uses.

D.3.1 Single Family Residential Infill

The adjusted total impervious percentage for existing single family residential zoned lots ranged from 45% to 70% within the Quibble watershed. An overview of an average single family residential lots impervious coverage can be seen in Image D-1.

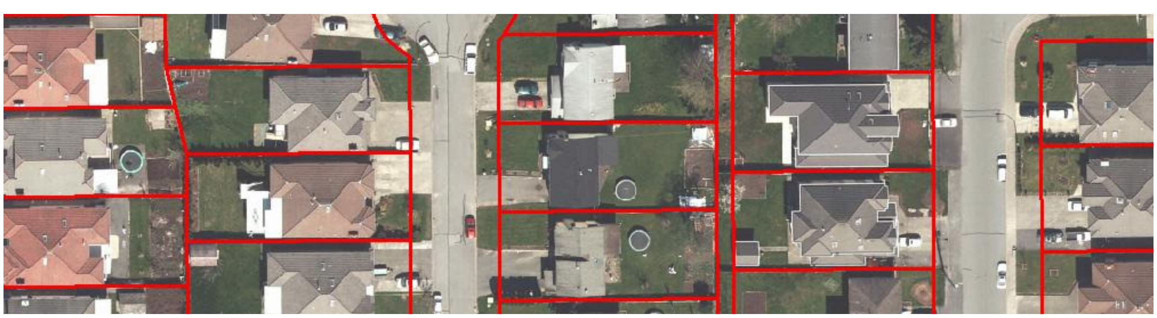

Image D-1: Existing Single Family Residential Land Use.

Appendix D – Hydrologic and Hydraulic Modelling

The total impervious percentage for single family residential zoned lots after infill is expected to range from 70% to 90%. The lots shown in Image D-2 below were zoned in 2011 and are outside of the Quibble Creek watershed but they provided a good example of the expected increase in the total impervious coverage.

Image D-2: Future Single Family Residential Land Use (Infill).

D.4 PC SWMM Model Development

Model Network

The model includes most storm sewer pipes, culverts, and watercourses within the Quibble Creek watershed as supplied by the City in their GIS databases. Nodes in the model consist of manholes, intakes, outfalls, and junctions. There was some missing or inaccurate information in the database including:

- Missing attribute information such as pipe sizes, inverts, and manhole rim elevations. Where this information was not available from the City, it was estimated based on nearby pipe information. Invert elevations were linearly interpolated from nearby entities.
- Missing pipe connections. Where this information was not available from the City, it was estimated based on nearby pipe information.

The drainage system includes:

Appendix D – Hydrologic and Hydraulic Modelling

- 66 km of pipes
- 1541 manholes/nodes/junctions
- Quibble Creek and its tributaries (KGH Tributary, 135 St. Tributary, and 142 St. Tributary)

Creek cross sections were taken from the LIDAR data provided by the City.

Channel and conduit roughness values were assigned based on typical values for the various conduit materials.

Figure D-5 shows an overview of the Quibble Creek model network.

Model Catchments

The Quibble Creek drainage area was divided into legal catchments and road catchments.

Data for the legal developed catchments was taken from the City's cadastral landuse GIS mapping. Before importing the data into the PC SWMM model, each parcel was paired with a node representing a manhole, a junction, or an end of a culvert.

Since the City's GIS database did not have right-of-ways defined as small parcel sized catchments, these were split using a Thiessen polygon methodology. This method involves using a GIS algorithm. The algorithm takes all the manholes used in the model and allocates areas to each one by determining which areas are closer to a particular manhole than any other.

In total, 3084 legal catchments and 1788 road catchments were created and imported into the PC SWMM model. Catchments were assigned the following attributes:

- slopes, using digital elevation mapping (DEM) information;
- existing land use impervious percentage, using the City of Surrey's GIS information for legal catchments;
- impervious percentage for future land use scenarios, using the City's OCP Zoning; and
- groundwater parameters based on soils mapping.

Groundwater and Soil Parameters

The groundwater feature of PC SWMM was used to better estimate the groundwater and interflow portions of the runoff hydrograph. Infiltration rates, soil depths, and soil hydraulic conductivity inputs were based on previously used values and/or typical values for parameters.

Figure D-6 shows the surficial geology of the Quibble Creek Basin that was used to determine soil parameters.

Appendix D – Hydrologic and Hydraulic Modelling

D.5 Model Calibration

Introduction

The 5-minute rainfall data from the Kwantlen Park and Surrey Municipal Hall rain gauge stations were used for the calibration and validation. Calibration and validation events were chosen by selecting significant storm events with the fewest data gaps.

Model calibration involved the adjustment of parameters, within reasonable ranges, until a set of objectives was met. The Quibble Creek model was calibrated to all respects of the runoff hydrograph (peak flow, volumes, the receding portion of the hydrograph from groundwater)

A two year continuous rainfall containing five significant dry weather and wet weather storms were modeled. See table D-2 for the dates and return period of the events..

Table D-2: Storm Events Modelled for Calibration

Date	Storm Event
6th May 2009	(2- to 5-year 15-minute and 2-hour
13th August 2009	10- to 15-year 2-hour, 25- to 50-year 5-minute and 1-hour, 50- to 100-year 10- and 30-minute
6th April 2008	2- to 5-year 2-hour
10th March 2007	2-year 6-hour, 5- to 10-year 12- and 24-hour,
2nd-4th December 2007	2- to 5-year 1-, 2-, and 24-hour, 5- to 10-year 6- and 24-hour, 25- to 50-year 6- and 12-hour

For each event, large differences between modeled and observed peak flows and modeled and observed volumes were observed. The flow volumes from the observed flow were significantly less than the rainfall volumes from the catchment. The average loss in volume between the recorded rainfall depth over the Quibble catchment and the observed flow at the outfall of the catchment averaged 44% over the five storm events. The average loss in volume between the recorded rainfall depth over the Quibble catchment and observed flow averaged 29% for a 2 year period of continuous modeling of storm events (Jan 1st 2007 – Jan 1st 2009). This volume loss indicates that the catchment's effective impervious percentage is lower than the total impervious percentage.

This large difference between the recorded rainfall depth and the observed flow has also been observed in two hydraulic storm water models previously built for the Quibble Creek catchment (KWL 1998 and EarthTech 2001). The difference in volumes maybe due to non-uniform rainfall across the Quibble Creek catchment or it may indicate that the catchment's effective impervious percentage is lower than the total impervious percentage.

The August 13th, 2009 dry weather summer storm event (unsaturated peaty soils) recorded a 74% loss of rainfall volume between the recorded rainfall depth and gauged flow.

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The March 6th, 2007 wet weather winter storm event (saturated peaty soils) recorded a 12% loss of rainfall volume between the recorded rainfall depth and gauged flow.

The calibration process was completed using the March 6, 2007 storm event that occurred during the saturated soil conditions.

Wet Calibration Event

The March 6, 2007 storm was used as the wet event calibration. This was a 5-year 6-hour storm event. The volume of modelled flow was approximately 10% less than the recorded rainfall volume input into the model. The evaporation losses in the model were negligible over the period of this storm. The modelled peak flows during this event were approximately 2% higher than the recorded flows. During the calibration of the model, the percentage impervious of catchments with low impervious coverage located on sand and silt/clay were adjusted to replicate the observed flow rates at the 88th Avenue flow station. The changes made to the impervious coverage for each soil type are outlined in Section D.3. The wet event calibration is presented in Image D-3.

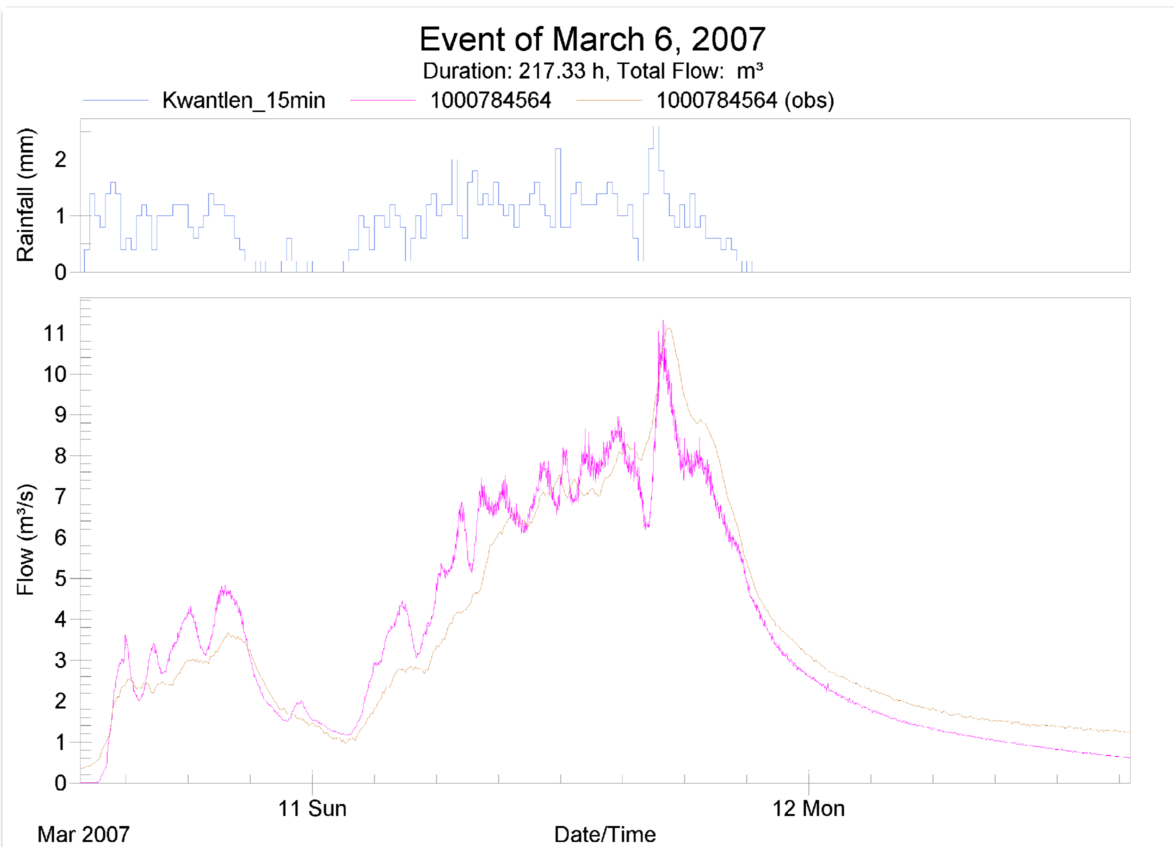

Image D-3: Wet Event Calibration (March 2007)

Appendix D – Hydrologic and Hydraulic Modelling

D.6 Design Storms

The calibrated model was used to simulate the 2-, 5-, 10-, and 100-year return period 1-, 2- 6-, 12-, and 24-hour duration design events and to determine governing peak flows and volumes for each conduit. The design rainfall was sourced from the City of Surrey Design Criteria Manual (2004). Table D-3 shows the design storm precipitation totals for all modelled events.

Table D-3: Design Storms for Quibble Creek

Duration	2-year Total Rainfall (mm)	5-year Total Rainfall (mm)	10-year Total Rainfall (mm)	100-year Total Rainfall (mm)
1-hour	10.90	13.90	15.80	22.00
2-hour	16.10	19.80	22.20	29.80
6-hour	31.61	37.30	41.00	59.79
12-hour	46.90	57.00	63.69	84.51
24-hour	64.62	82.91	95.01	133.00

All events were modelled using saturated soil conditions typical of winter conditions.

D.7 Peak Flow Estimates

Unit peak flows from the calibrated existing model were checked against unit flows estimated for similar creeks in the Lower Mainland. Table D-4 shows the unit peak flow comparison.

Table D-4: Unit Peak Flow Comparison

Location	Peak Flow (L/s/ha)			
	2-year	5-year	10-year	100-year
Largely developed Catchments				
Quibble Creek ISMP – 656ha – 47% EIA	13	19	21	24
Hyland Creek – 466ha – 58% EIA*	12	16	NA	27
Bear Creek – 1147ha – 52% EIA*	12	21	NA	43

* *Data referenced from "Pilot Stormwater Quantity Monitoring Program", 1998, Kerr Wood Leidal*

In general, the unit flows from the model were in line with estimates for similar creeks.

D.8 Future Mitigated Model

The mitigated model was built to evaluate the effectiveness of best management practices and specifically the application of source controls. Different source controls are selected for different land

Appendix D – Hydrologic and Hydraulic Modelling

uses and areas within the watershed based on feasibility of implementation. These source controls will essentially help reduce the effective impervious area.

Target effective impervious areas for each land use were applied to the hydrologic model for the mitigated future land use scenario. Two other scenarios were also simulated using the simplified model; one for existing land use conditions and also, one for unmitigated future land use conditions for comparison purposes.

Model Network

The future mitigated hydraulic model was created based on the future land use model. This is a simplified SWMM model that contains some major trunk storm mains and creeks. The simplification of the model allowed for efficient long term continuous storm model simulation.

The future mitigated model drainage system includes:

- 1.4 km of storm main pipes
- 170 manholes/nodes/junctions
- Quibble Creek and its tributaries (KGH Tributary, 135 St. Tributary, and 142 St. Tributary)

Figure D-7 shows an overview of the Quibble Creek future mitigated model network.

Model Catchments

The legal catchments and road catchments from the future land use model were merged into major sub-catchments.

Each major sub-catchment was paired with an outlet node. All hydraulic structures upstream of these outlet nodes were deleted from the future land use model.

In total, 24 lumped catchments were created in the PC SWMM model. Catchments were assigned the following attributes:

- slopes, using digital elevation mapping (DEM) information;
- future land use impervious percentage (based on an area weighted average impervious percentage of the legal/road catchments that were lumped into the single sub-catchment); and
- groundwater parameters based on soils mapping.

Figure D-7 shows an overview of the Quibble Creek future mitigated catchments.

Groundwater and Soil Parameters

The groundwater feature of PC SWMM was used to better estimate the groundwater and interflow portions of the runoff hydrograph. Infiltration rates, soil depths, and soil hydraulic conductivity inputs were based on previously used values and/or typical values for parameters.

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Mitigated Model Calibration

The future mitigated model was calibrated to ensure that the model would reproduce the flow pattern as recorded in the future land use hydraulic model.

The flow length attribute was adjusted until peak flow, volumes and the receding portion of the hydrograph from groundwater made a reasonable match.

Image D-4 is a plot of the calibrated flow for the future mitigated model at the link (1000784564) upstream of the study areas outfall.

Appendix D – Hydrologic and Hydraulic Modelling

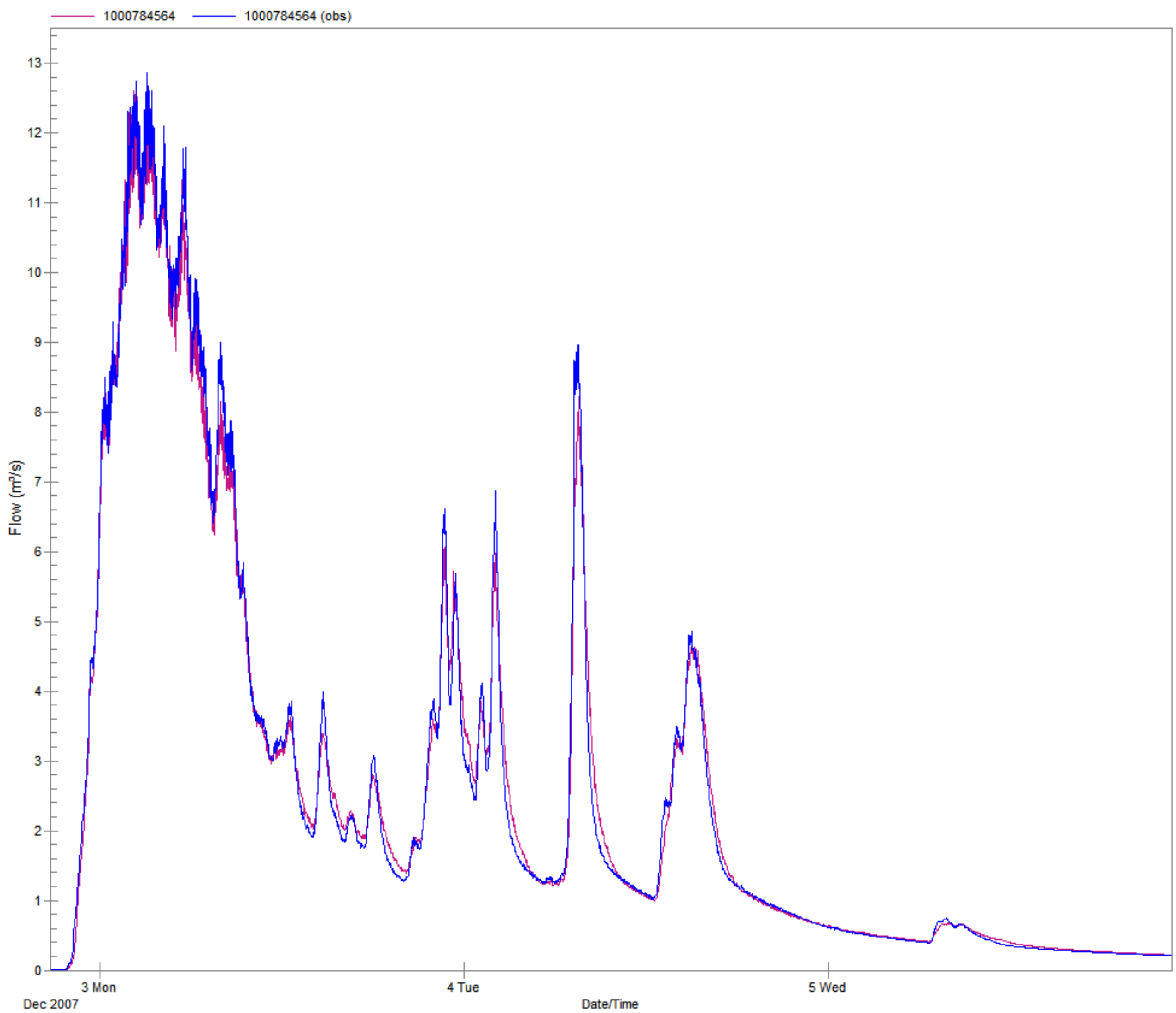

Image D-4: Future Mitigated Model Calibration

Continuous Model

The calibrated model was used to simulate a continuous historical rainfall period (1985 – 1998) and to produce a flow exceedance duration curve for the existing, future and future mitigated scenarios. The

Appendix D – Hydrologic and Hydraulic Modelling

rainfall data was sourced from Kwantlan Park rain gauge (1 hour data). Figure D-8 shows the exceedance duration curve for Quibble Creek.

Exceedance duration curves generally show the amount of hours any given flow occurs for a flow data set. In catchments that have been developed, the curves often show higher flows for more hours under the developed condition, while pre-developed conditions often have lower flows occurring for more hours. The exceedance duration curves for Quibble Creek were developed using 13 years (113,960 hours) of data.

The exceedance duration curve shows that the existing scenario has slightly more hours of low flow events then the future curve and that overall the future curve has more hours at any given flow then the existing flow. For example, the existing 2-year recurring storm generates a peak flow of 8.9 m^3/s for 4.8 hours under existing conditions. The same existing 2-year storm generates a peak flow of 8.7 m^3/s for 16.5 hours under future watershed conditions, a 3.5-fold increase in occurrence. The future conditions 2-year recurring storm generates a peak flow of 14.5 m^3/s, which does not occur during the modelled 13 years of data.

The mitigated curve matches the existing curve for the lower, more frequent flows, then slowly decreases to below the existing curve for the higher, less frequent flows. This shows that the source controls are capable of reducing the smaller, more frequent events to the existing level and higher, less frequent events to below the existing level.

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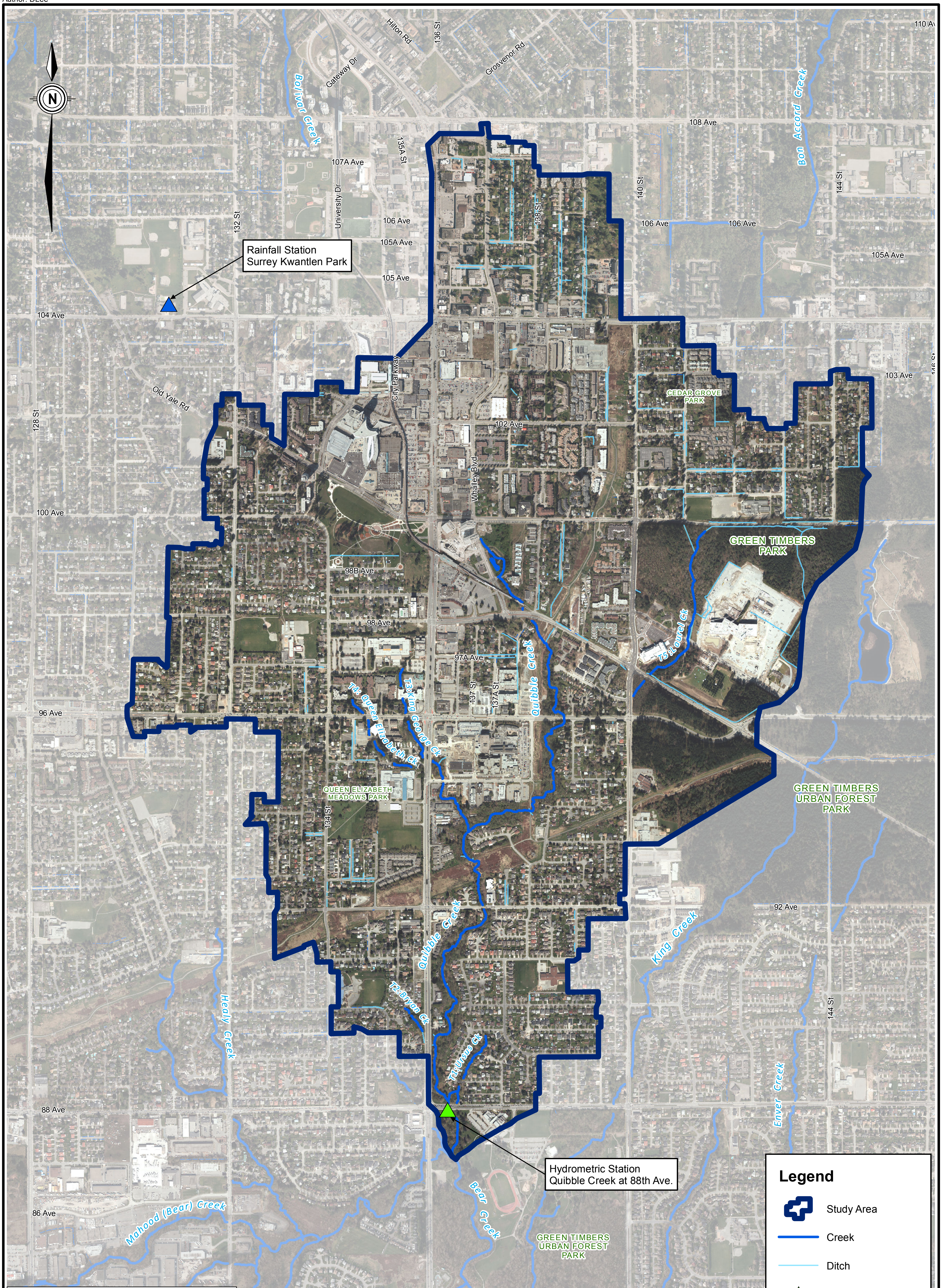

Reference: Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.

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Rain Gauge and Flow Monitoring Station Locations

Figure D-1

Stage Discharge Information: Numerical

Site: Quibble Creek at 88th Avenue

Monitoring Station: 8

Hatfield CONSULTANTS

Period of Use:	1/1/2010 0:00	Open ended		
Remarks:	Curve was shifted from WSC curve No. 14.00 using 2010 data			
Date Created:	2/16/2011 13:00			
Updated by:	Steven Guenther	Date:	1/6/2012	
Approved by:	Heidi Biberhofer	Date:	2/8/2012	

Offset	Equation
0.199	15.812 * (SG-0.199)^1.836

Gauge Height	Discharge	Slope
m	m³/s	
0.205	0.001	
0.219	0.012	1.27273
0.240	0.045	0.63636
0.250	0.067	0.45455
0.261	0.096	0.37931
0.269	0.120	0.33333
0.276	0.143	0.30435
0.280	0.157	0.28571
0.289	0.190	0.27273
0.306	0.261	0.23944
0.317	0.312	0.21569
0.344	0.456	0.18750
0.355	0.522	0.16667
0.405	0.869	0.14409
0.429	1.064	0.12308
0.458	1.324	0.11154
0.479	1.525	0.10448
0.501	1.748	0.09865
0.546	2.247	0.09018
0.600	2.918	0.08048
0.650	3.609	0.07236
0.700	4.364	0.06623
0.725	4.766	0.06219
0.750	5.183	0.05995
0.775	5.616	0.05774
0.800	6.064	0.05580
0.825	6.528	0.05388
0.861	7.222	0.05187

Stage Discharge Information: Graphical

Site: Quibble Creek at 88th Avenue

Monitoring Station: 8

Hatfield CONSULTANTS

Period of Use:	1/1/2010 0:00	Open ended		
Remarks:	Curve was shifted from WSC curve No. 14.00 using 2010 data			
Date Created:	2/16/2011 13:00			
Updated by:	Steven Guenther	Date:	1/6/2012	
Approved by:	Heidi Biberhofer	Date:	2/8/2012	

Rating Point
Historic Measurement
Current Measurement

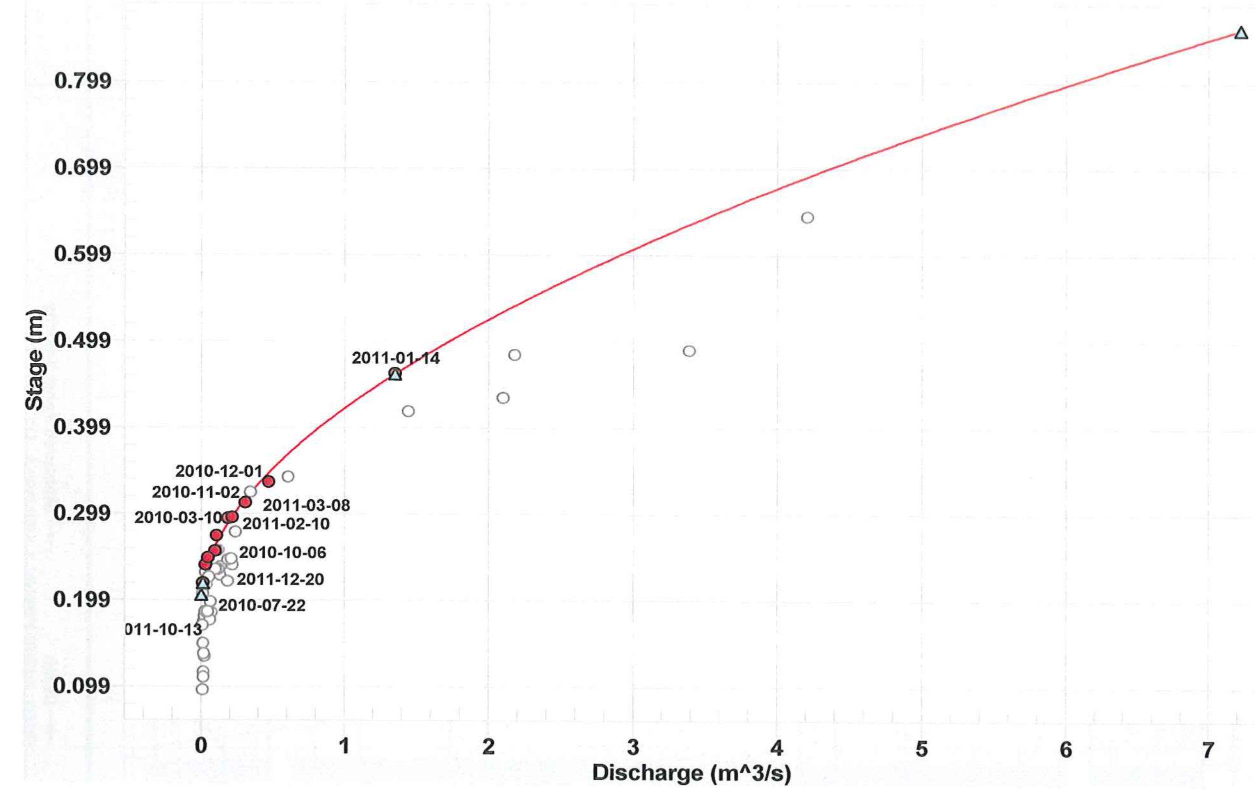
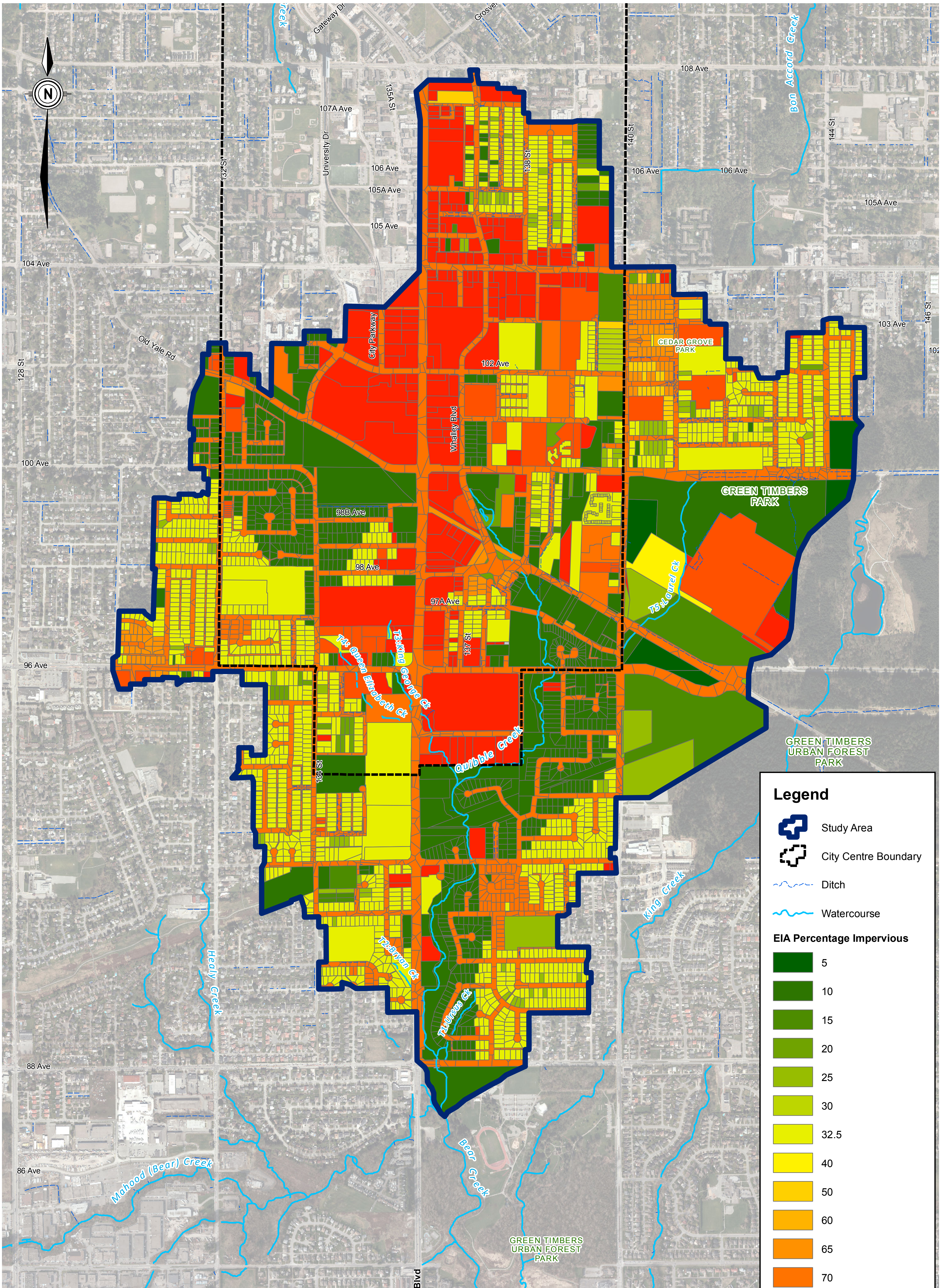


Figure D-2



Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.

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Existing Landuse EIA

Figure D-3

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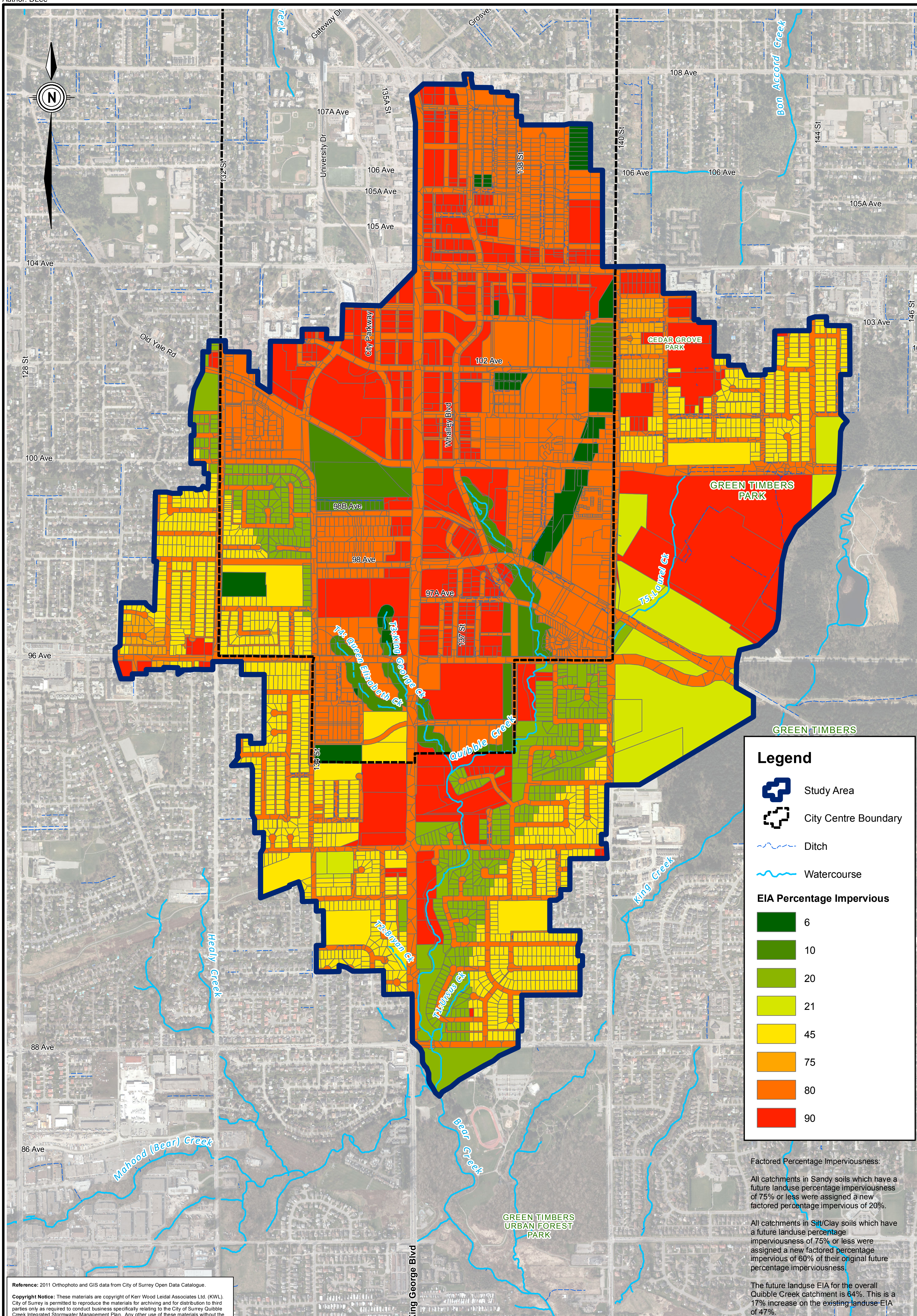

Factored Percentage Imperviousness:

All catchments in Sandy soils which have a future landuse percentage imperviousness of 75% or less were assigned a new factored percentage impervious of 20%.

All catchments in Silt/Clay soils which have a future landuse percentage imperviousness of 75% or less were assigned a new factored percentage impervious of 60% of their original future percentage imperviousness.

The future landuse EIA for the overall Quibble Creek catchment is 64%. This is a 17% increase on the existing landuse EIA of 47%.

Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.

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Future Unmitigated Landuse EIA

Figure D-4

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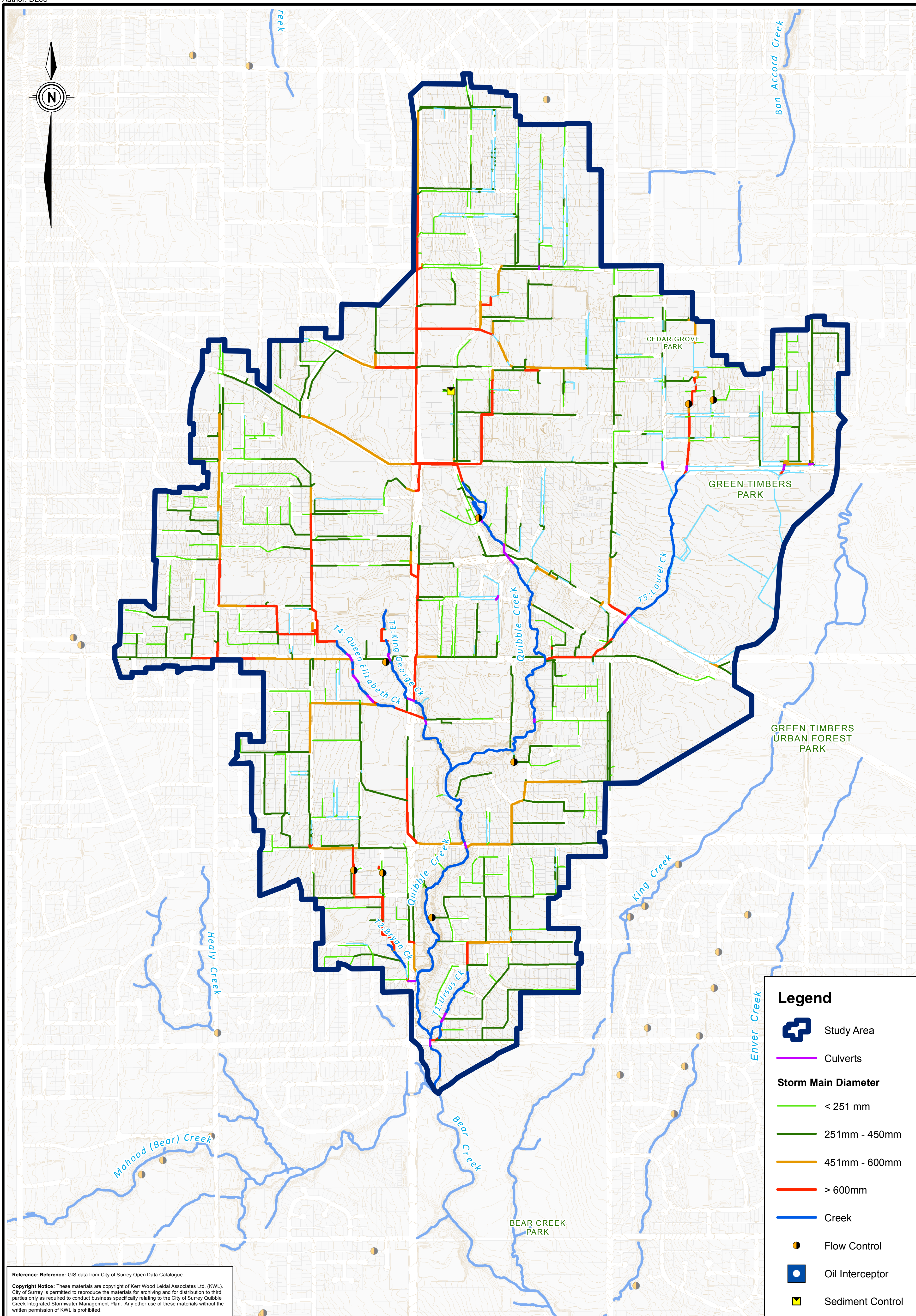

Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

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Modeled Network

Figure D-5

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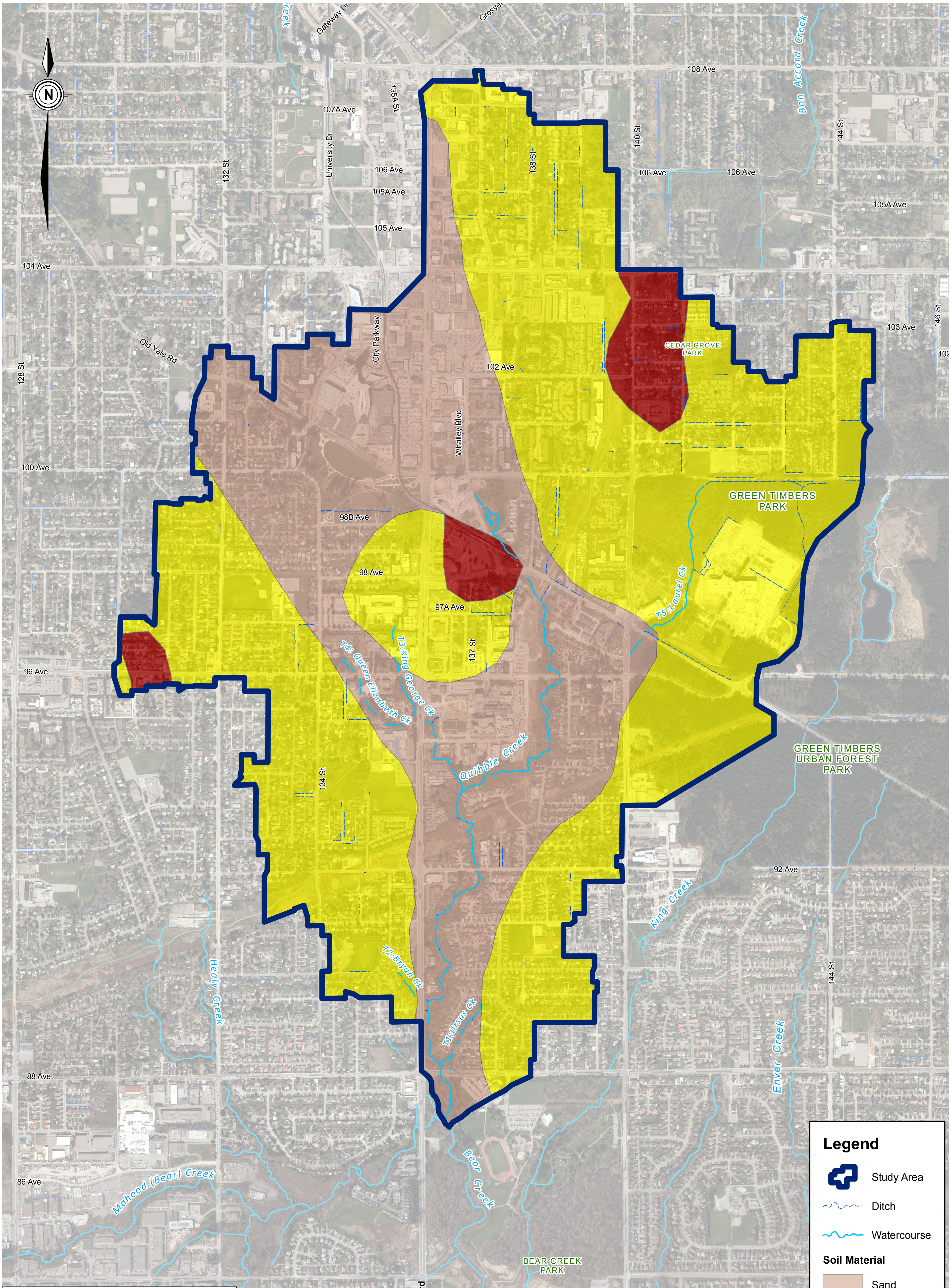

Reference: 2011 Orthophoto and GIS data from City of Surrey Open Data Catalogue.
Surficial Geology Information: Natural Resource Canada
and the Geological Survey of Canada
This information is not warranted as to its accuracy by Kerr Wood Leidal Associates. This information is provided for illustrative purposes only.

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Soils Map

Figure D-6

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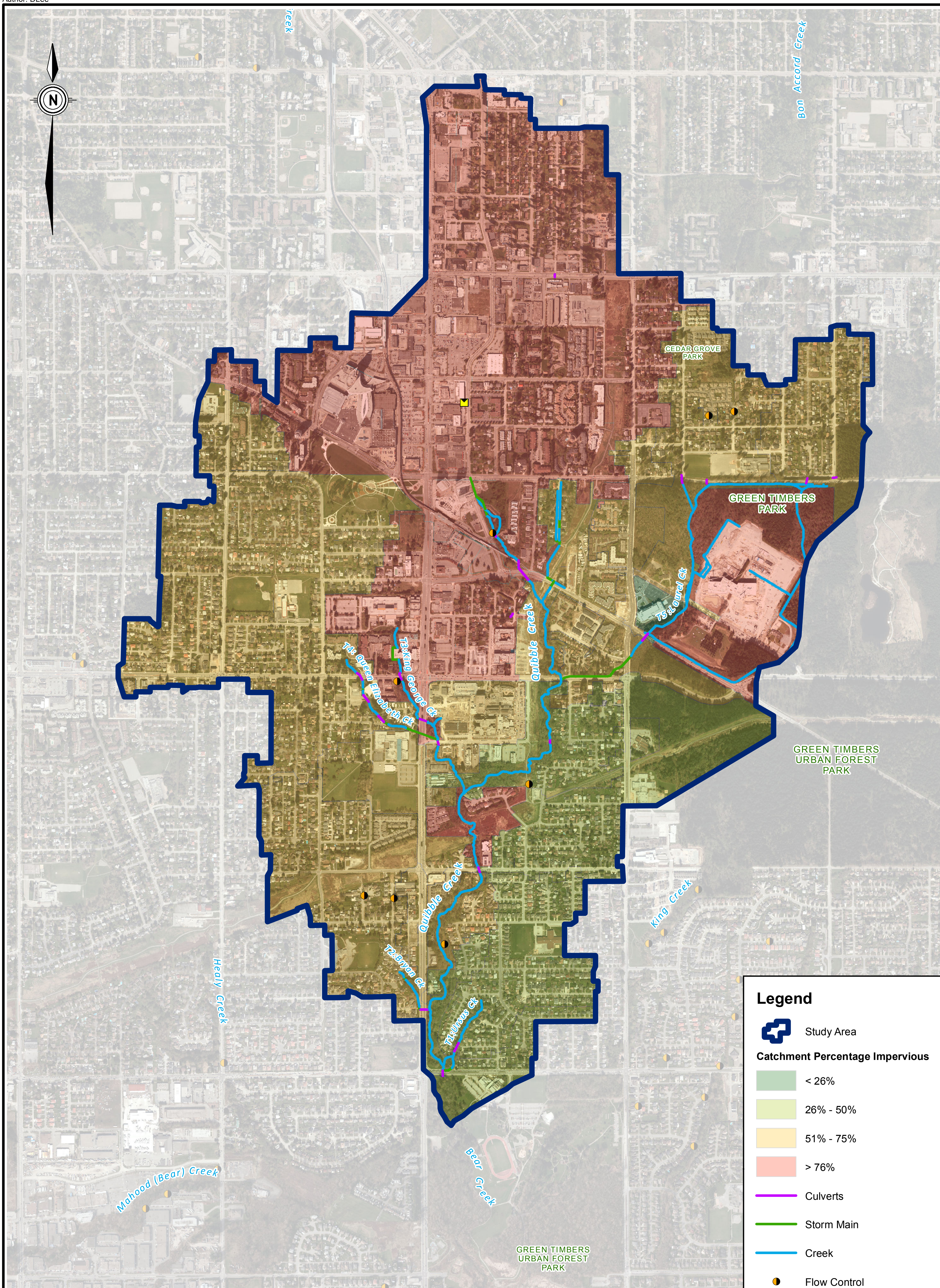
Author: DLee



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

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City of Surrey
Quibble Creek Integrated Stormwater Management Plan

Project No. 471-239
Date February, 2014

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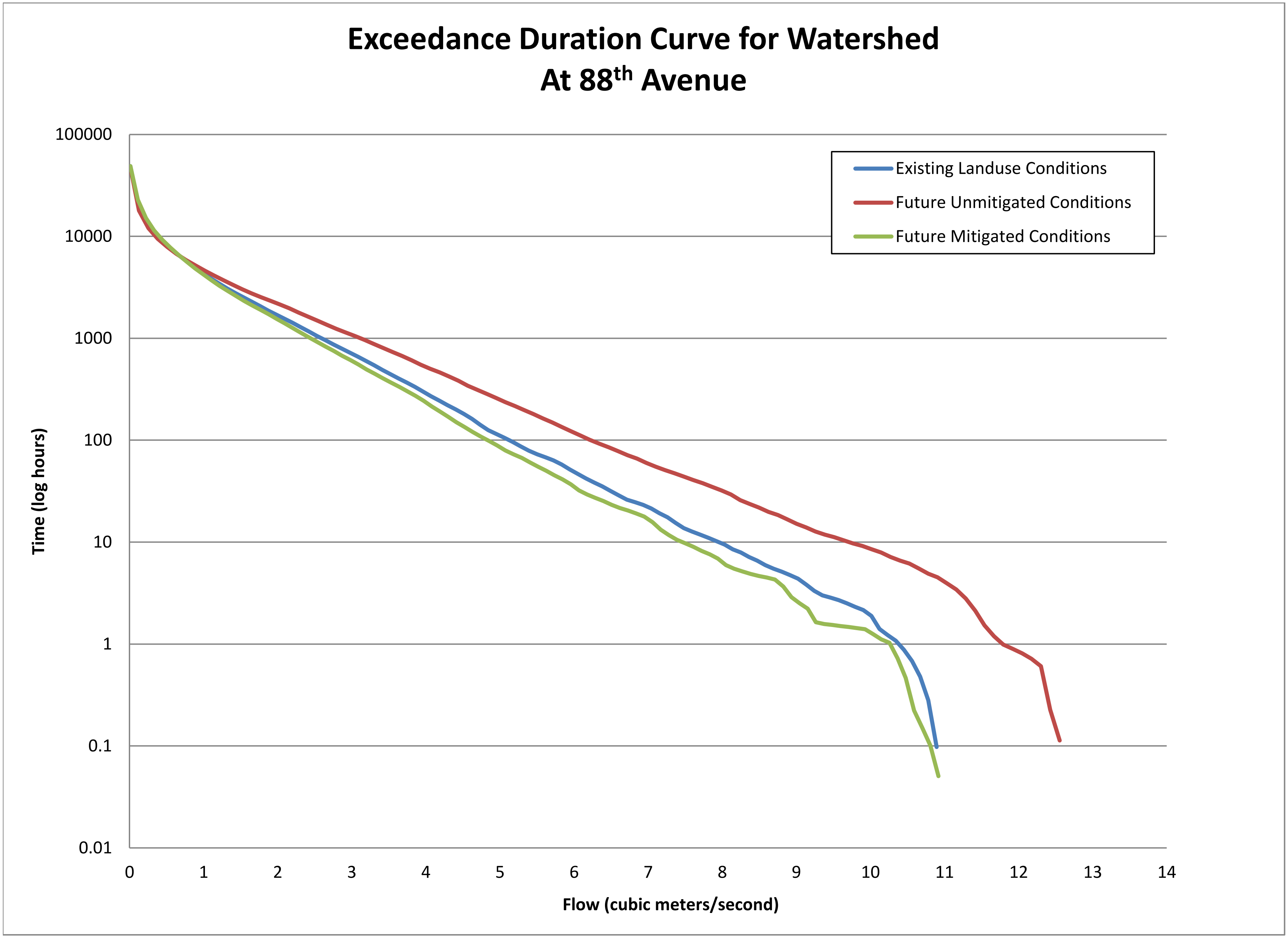
Future Mitigated Modeled Network and Catchments

Figure D-7



Kerr Wood Leidal Associates Ltd.

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Figure D-8

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Appendix E

Hydrotechnical/Drainage Assessment

Appendix E – Drainage Assessment

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E Drainage Assessment

E.1 Introduction

This section summarizes the assessment of the drainage system under different design storm events for the existing and future OCP land use conditions. The assessments did not include pipe condition or age and used instantaneous peak flows not adjusted for climate change.

E.2 Urban Storm Sewers

Results from modeling the watershed's pipe network highlighted a number of areas where pipes are undersized and surcharging.

Minor System

The drainage system was assessed to determine its ability to convey the minor flow, generated by the 5-year return period rainfall event. The following three criteria were used to determine whether each sewer is undersized:

- Modelled instantaneous peak flow is larger than pipe capacity under free-flowing conditions;
- Pipe surcharged for longer than 15 minutes; and
- Water surcharged higher than 0.3 m above the crown of the pipe.

Existing Conditions Minor System

Figure E-1 schematically shows the pipes that exceeded the three criteria during the existing conditions 5-year event model runs. Table E-1 and E-2 lists the pipes that exceeded the minor system criteria, listed above. 19 pipes exceeded the criteria of the 1,424 total conduits in the watershed.

Appendix E – Drainage Assessment

Table E-1: Storm Sewers Undersized for 5-Year Event Existing Land Use Flow and Flooding

Conduit ID	Existing 5-Year Flow (m3/s)	Future 5-Year Unmitigated Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)
1000862290	0.07	0.09	200	375	28
1000862293	0.06	0.12	200	375	3
1000752493	0.13	0.19	250	375	34
1000864709	0.13	0.2	250	375	19
1000798043	0.06	0.12	250	375	20
KWL_1444	0.06	0.12	250	375	6
1000769361	0.06	0.12	200	300	21
KWL_1339	0.06	0.12	250	300	10

Notes:
1. Conduits shaded grey above identifies conduits where pipe data such as inverts, slope and/or pipe diameter were assumed.

Table E-2: Storm Sewers Undersized for 5-Year Event Existing Land Use Flow and Surcharging

Conduit ID	Existing 5-Year Flow (m3/s)	Future 5-Year Unmitigated Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)
1000758319	0.20	1.10	375	900	12
1000745657	1.25	2.55	750	1200	21
1000758375	0.85	1.45	600	900	31
1001083119	0.07	0.11	300	525	13
1000758140B	0.07	0.16	200	375	57
1000758374	0.85	1.44	600	750	21
1000746169	0.23	0.34	300	450	53
KWL_1352	0.13	0.22	250	375	25
1000758140A	0.06	0.12	200	300	61
1000824112	0.19	0.19	300	375	64
1000824111	0.17	0.17	300	375	79

Notes:
1. Conduits shaded grey above identifies conduits where pipe data such as inverts, slope and/or pipe diameter were assumed.

Appendix E – Drainage Assessment

Future Conditions Minor System

An additional 122 pipes have been flagged as being under capacity in the future land use scenario models. These flagged pipes are adequately sized for the existing conditions but would need to be upgraded to accommodate the future conditions flows. The future conditions models did not account for potential detention that may be implemented as part of ongoing development in the watershed. Fewer pipes would likely need replacing if detention is incorporated into future development plans.

Figure E-2 shows the flagged pipes and Table E-3 and Table E-4 list them.

Table E-3: Storm Sewers Undersized for 5-Year Event Future Land Use Flow, 2 Dia. Upgrade

Conduit ID	Existing 5-Year Flow (m3/s)	Future 5-Year Unmitigated Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)
1000743277	3.59	8.70	1200	2700	7
1000767201	1.31	1.81	1200	1950	10
1000769409	0.68	1.19	450	750	2
1000752394	0.28	0.73	450	750	98
1000746111	0.10	0.13	450	750	58
1000758320	0.05	0.38	375	675	53
1000755919	0.02	0.08	250	525	44
KWL_1445	0.06	0.13	250	525	8
1000758071	0.05	0.16	200	450	13
1000765051	0.19	1.21	600	900	15
1000758331	0.30	2.07	600	900	15
1000758136	0.10	0.81	450	675	18
1000752392	0.47	1.04	450	675	56
1000746258	0.04	0.05	300	525	56
KWL_1355	0.08	0.29	300	525	7
KWL_1356	0.08	0.24	300	525	79
1000764585	0.05	0.14	250	450	42
1000755450	0.04	0.11	250	450	54
KWL_1354	0.06	0.16	250	450	7
KWL_LINK_27	0.04	0.15	200	375	53
1000757960	0.00	0.00	75	200	27
1000758139	0.21	0.74	750	1050	20

Appendix E – Drainage Assessment

Conduit ID	Existing 5-Year Flow (m3/s)	Future 5-Year Unmitigated Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)
KWL_1452	1.30	2.52	750	1050	12
1000765081	0.53	0.71	600	750	68
1000758135	0.24	0.70	525	675	28
1000758134	0.09	0.47	450	600	24
1000758424	0.24	0.35	450	600	47
1000758318	0.13	0.32	450	600	96
1000758145	0.07	0.15	300	450	17
1000752395	0.19	0.46	300	450	43
1000758386	0.14	0.22	300	450	87
1000752399	0.19	0.45	300	450	58
1000758242	0.05	0.07	250	375	8
1000768282	0.11	0.33	250	375	6
1000758083	0.03	0.10	250	375	17
1001121975	0.06	0.12	250	375	11
1000755471	0.06	0.16	250	375	73
1000752498	0.03	0.14	250	375	15
KWL_1340	0.07	0.17	250	375	25
1000745628	0.06	0.09	250	375	10
KWL_1447	0.07	0.15	250	375	7
KWL_1456	0.05	0.09	250	375	10
KWL_1443	0.05	0.14	250	375	11
KWL_1457	0.05	0.07	250	375	7
1000752489	0.02	0.04	200	300	17
1000758361	0.03	0.04	200	300	4

Notes:
1. Conduits shaded grey above identifies conduits where pipe data such as inverts, slope and/or pipe diameter were assumed.

Appendix E – Drainage Assessment

Table E-4: Storm Sewers Undersized for 5-Year Event Future Land Use Flow, 1 Dia. Upgrade

Conduit ID	Existing 5-Year Flow (m3/s)	Future 5-Year Unmitigated Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)
1000758151	0.61	0.76	900	1050	25
1000745268	0.61	0.90	900	1050	43
1000746316	0.46	0.86	900	1050	114
1000758376	1.24	2.06	900	1050	32
1000746297	0.35	0.50	750	900	15
1000746241	1.11	1.75	750	900	76
1000763003	0.36	0.53	750	900	48
1001170198	0.62	1.17	600	675	11
1000765086	0.58	1.13	600	675	22
1000755449	0.23	0.47	600	675	76
1000758420	0.47	0.62	600	675	44
1000758452	0.58	1.13	600	675	80
1000765021	0.48	0.63	600	675	15
1000755453	0.24	0.48	600	675	77
1000758480	0.70	1.26	600	675	51
1000757945	0.14	0.18	525	600	11
1000751876	0.12	0.23	450	525	75
1000758323	0.19	0.25	450	525	46
1000765079	0.55	0.86	450	525	49
1000758422	0.37	0.49	450	525	40
1000743316	0.43	0.44	375	450	29
1000758351	0.13	0.17	375	450	52
1000758402	0.14	0.23	375	450	75
1000766448	0.06	0.13	375	450	40
1000752344	0.09	0.18	375	450	104
1000743375	0.06	0.15	300	375	14
1000758148	0.09	0.12	300	375	123

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Conduit ID	Existing 5-Year Flow (m3/s)	Future 5-Year Unmitigated Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)
1000767414	0.09	0.12	300	375	11
1000758487	0.08	0.10	300	375	90
1000752548	0.14	0.21	300	375	47
1000752497	0.10	0.20	300	375	111
1000762875	0.06	0.14	300	375	34
1000755972	0.04	0.06	300	375	54
1000758226	0.05	0.07	300	375	27
1000746177	0.24	0.35	300	375	16
1000752466	0.12	0.22	300	375	47
1000755945	0.04	0.06	300	375	81
1000769389	0.07	0.09	300	375	96
1000764587	0.07	0.17	300	375	77
1000752488	0.07	0.14	300	375	56
1000743383	0.08	0.26	300	375	2
1000765075	0.06	0.10	300	375	15
1001083120	0.09	0.21	300	375	4
1000758247	0.05	0.07	300	375	108
1000762854	0.02	0.02	250	300	39
1000752455	0.03	0.03	250	300	13
1000758413	0.04	0.06	250	300	61
1000769401	0.06	0.08	250	300	42
1000743279	0.10	0.13	250	300	53
1000752404	0.05	0.08	250	300	124
1000765041	0.05	0.06	250	300	16
1000752461	0.04	0.05	250	300	41
1000762465	0.04	0.03	250	300	27
1000768213	0.03	0.10	250	300	11
1000755925	0.01	0.01	250	300	12
1000765070	0.07	0.09	250	300	8

Appendix E – Drainage Assessment

Conduit ID	Existing 5-Year Flow (m3/s)	Future 5-Year Unmitigated Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)
1000758404	0.10	0.13	250	300	12
1000768283	0.03	0.06	250	300	12
KWL_1446	0.02	0.09	250	300	21
KWL_LINK_20	0.08	0.10	250	300	75
1000755448	0.00	0.07	250	300	22
1000758074	0.02	0.05	250	300	13
1000751879	0.08	0.10	250	300	50
1000755916	0.01	0.05	250	300	72
1000769396	0.05	0.07	200	250	38
1000758381	0.02	0.02	200	250	11
1000862292	0.06	0.10	200	250	39
1000752458	0.02	0.03	200	250	32
1000746310	0.02	0.03	200	250	60
1000746326	0.04	0.06	200	250	44
KWL_1343	0.03	0.04	200	250	76
KWL_1344	0.04	0.05	200	250	5
1000758099	0.48	0.62	600	675	37
1000752345	0.10	0.08	375	450	54
1000752401	0.08	0.11	250	300	85
1000743284	0.10	0.13	250	300	24

Notes:
1. Conduits shaded grey above identifies conduits where pipe data such as inverts, slope and/or pipe diameter were assumed.
2. Conduits shaded green above identify conduits to be upsized due to upstream upgrade requirements.

When developing a capital works program for upgrading the storm sewer system, many of the pipes may not need to be upgraded immediately. They can continue to operate surcharged, and as they deteriorate and near the end of their design life, should be replaced with the recommended sizes at the end of their life cycle. Recommendations for upgrades and priorities are included in Appendix G.

Appendix E – Drainage Assessment

Major System

The major system is the conveyance system that carries large storms, greater than the 5-year event and up to the 100-year event. Road surfaces and daylighted sections of creeks make up the majority of the major system in this watershed. Additionally, culverts have been designated as part of the major system when they are between daylighted sections of the creeks. This is to ensure that major flows from the daylighted sections have a major flow route and do not cause damage to neighbouring properties.

Using the model results and field inventory, the culverts were assessed on their ability to pass the required 100-year peak flow while limiting surcharging and without flooding the land upstream. The assessment criteria were:

- Flooding above the ground for any duration with 100-year event instantaneous peak flow.

In each case, the proposed upgrades were sized for the greater of the existing or future scenario flow.

Existing Conditions Major System

Figure E-3 schematically shows the culverts that exceeded the criteria during the existing conditions 100-year event model runs. 4 culverts exceeded the criteria out of the 21 total culverts in the watershed.

Table E-5: Storm Sewers Undersized for 100-Year Event Existing Land Use Flow and Flooding

Conduit ID	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)
1000762498	5.06	13.72	1200	3000	13
1000743403	13.09	23.41	1500	2400	19
KWL_1453	1.92	4.17	750	1200	34
KWL_1454	1.65	4.17	750	1200	33

Notes:
1. Conduits shaded grey above identifies conduits where pipe data such as inverts, slope and/or pipe diameter were assumed.

Future Conditions Major System

An additional three pipes have been flagged as exceeding the criteria in the future land use scenario models. These flagged pipes are adequately sized for the existing conditions but would need to be upgraded to accommodate the future conditions flows.

Figure E-3 shows the flagged culverts and Table E-6 lists them.

Appendix E – Drainage Assessment

Table E-6: Storm Sewers Undersized for 100-Year Future Land Use Flow and Flooding

Conduit ID	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)
1000762497	9.43	31.08	2000	4000	10
1000746272	2.07	2.95	1050	1350	34
1000765058	0.59	1.08	900	1050	21

Notes:
1. Conduits shaded grey above identifies conduits where pipe data such as inverts, slope and/or pipe diameter were assumed.

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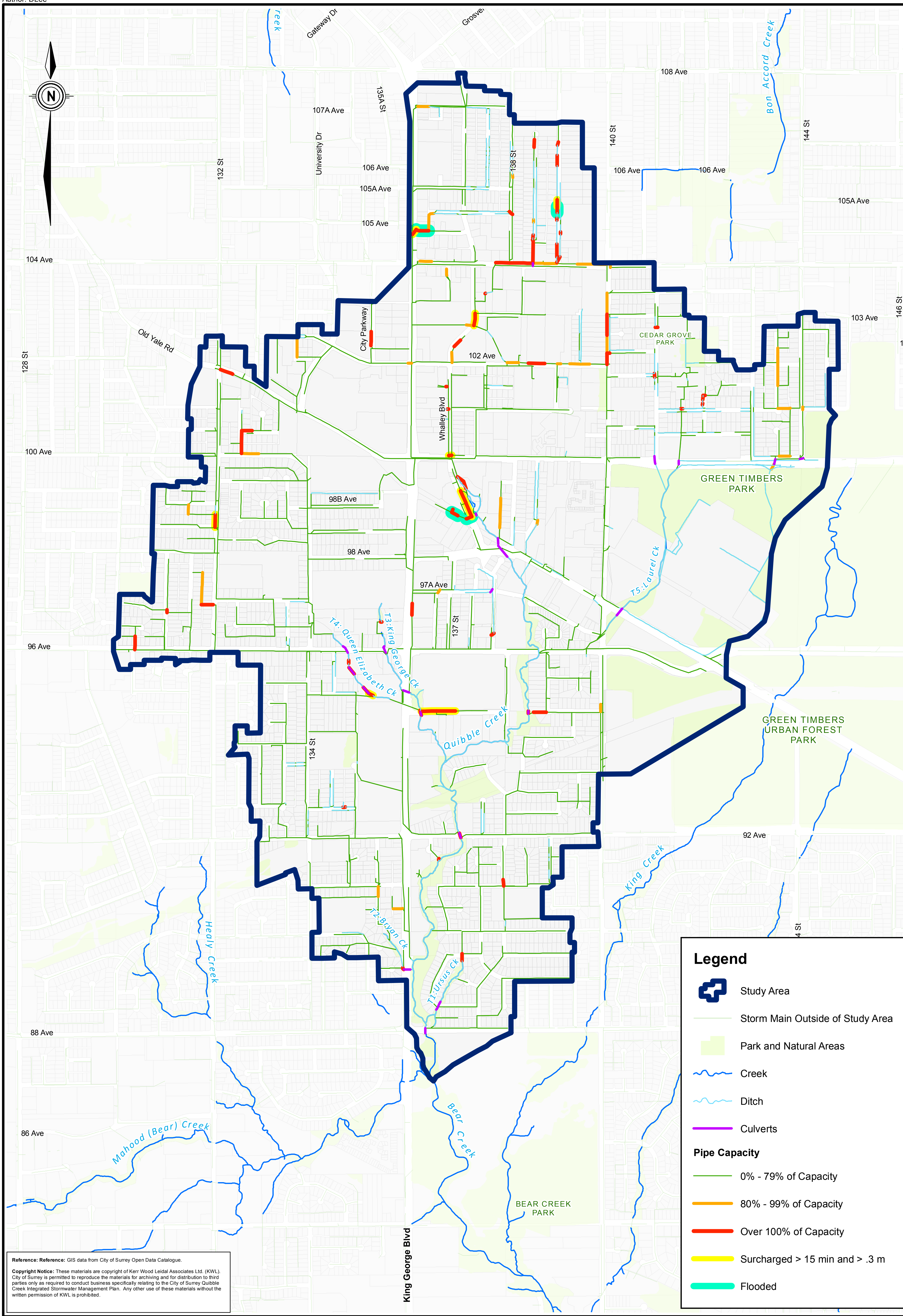
Author: DLee



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

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5-Year Existing Land Use Drainage Assessment

Figure E-1

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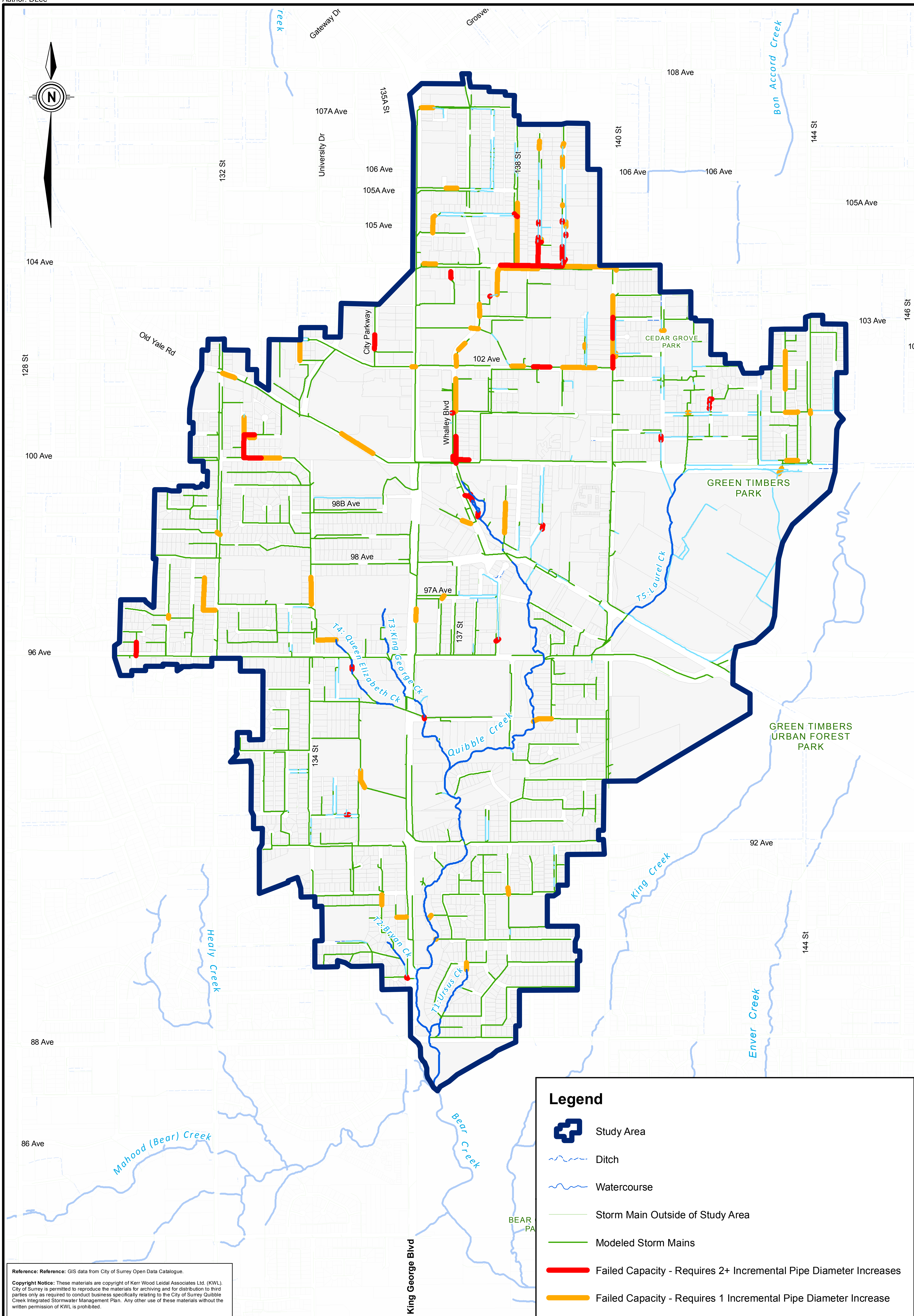

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City of Surrey
Quibble Creek Integrated Stormwater Management Plan

Project No.	Date
471-239	February, 2014

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5-Year Unmitigated Future Land Use Drainage Assessment

Figure E-2

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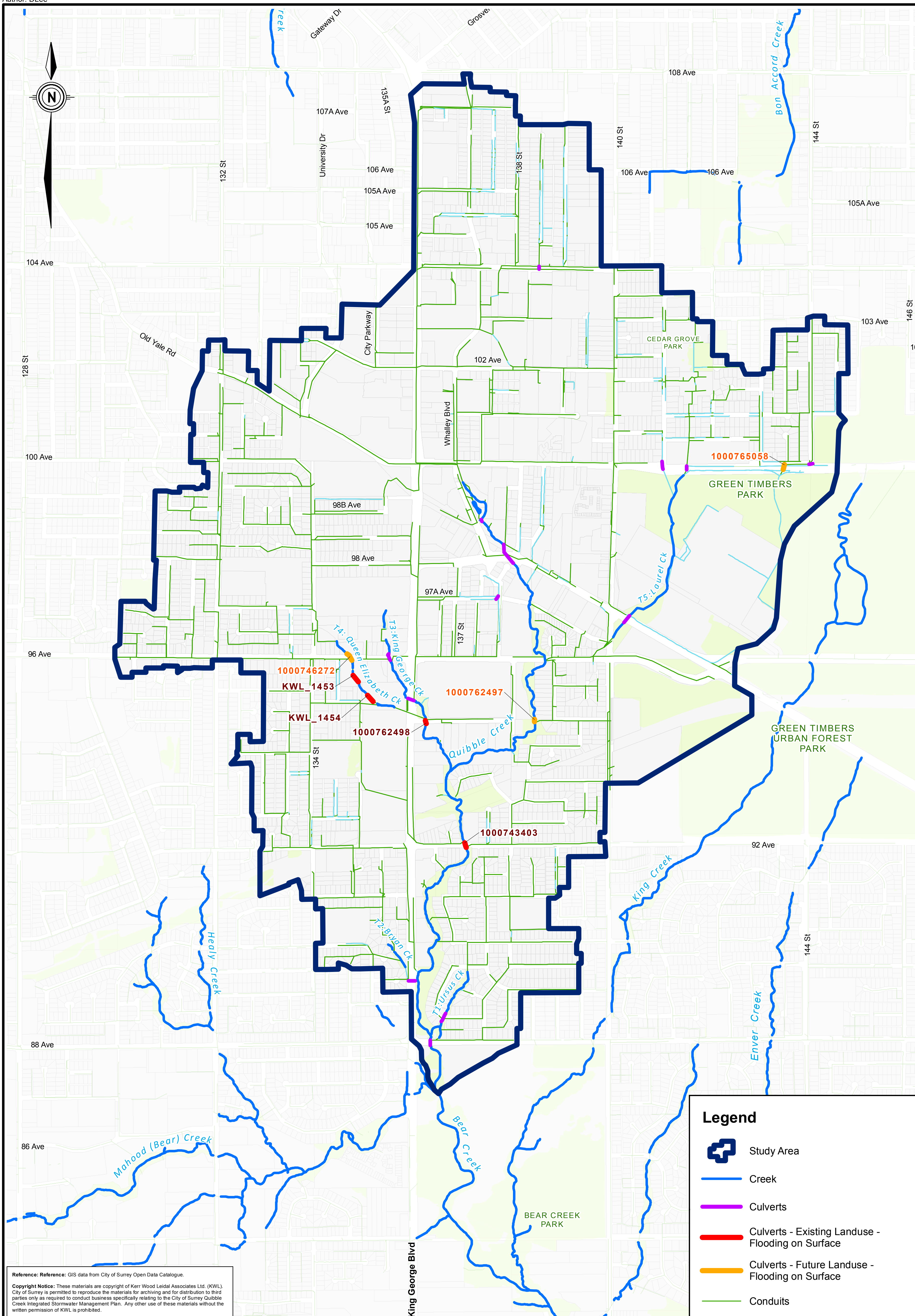

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City of Surrey
Quibble Creek Integrated Stormwater Management Plan

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471-239	February, 2014

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100-Year Existing and Future OCP Land Use Drainage Assessment

Figure E-3

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Appendix F

Stakeholder Process

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Greater Vancouver
200 - 4185A Still Creek Drive
Burnaby, BC V5C 6G9
T 604 294 2088
F 604 294 2090

Minutes of Meeting

MEETING DATE: October 11, 2012

LOCATION: Surrey City Hall

RE: **WATERSHED VISION WORKSHOP**
Quibble Creek ISMP
Our File 0471.239

ATTENDEES:

City of Surrey:
David Hislop, Project Engineer
Carrie Baron, Engineering
Stephen Godwin, Engineering Environmental Coordinator
Mary Beth Rondeau, Senior Planner
Preet Heer, Senior Planner
Ted Uhrich, Manager, Parks Research and Design
Don Luymes, Manager of Community Planning at City of Surrey
Pat Lau, Planner
Doug Merry, Parks Planning Technician OR Patrick Klassen, Parks and Recreation Planner?

Consultants:
Laurel Morgan, Chris Johnston, Sara Pour, KWL
Nick Page, Raincoast Applied Ecology

DISTRIBUTION: All attendees

Meeting Notes below are organized chronologically as discussed during the workshop. Key outcomes and actions from the meeting are shown in the column at the right and provide a quick summary of the items that will be brought forward for the next phase of the Quibble ISMP work.

Name	Discussion	Outcome/Action
1.0	**Introduction by CJ:** -This is the second of a series of three City meetings. The findings of this meeting will guide KWL's work for the remainder for the project. -Currently, the watershed is behaving better than it should be because it has disconnected impervious area. -The goal of this meeting is to establish a vision for the watershed to set the course for future action. -Question for this study is "What is the watershed going to look like 40 years from now?"	
2.0	**Presentation by LM covered the following topics:** -Existing watershed condition. -Quibble Creek as a showcase watershed– an urban watershed in good health. -Risks from future development. -Summary of goals from other documents that can serve as goals and visions for this ISMP.	

Name	Discussion	Outcome/Action
	-Possible vision and goal statements for the Quibble Watershed.	
2.1	**Workshop participants provided ideas and feedback for the vision.**	
CB	Although watershed condition is better than expected, it is not as good as it should be. Watershed could be doing better.	Goal: watershed health should be improved
CB	We can get more riparian on redevelopment. We want to maintain and enhance the riparian area and not just hold the line.	Goal: maintain and enhance the riparian area
TU	Park Acquisition? -Small pockets of parks are proposed throughout the City Centre and the plans are being revisited now. -Green Timbres provides green space. It is close to the City Centre but outside the boundary.	Goal: increase public space and park area
TU	Acquiring space for infiltration and storage facilities in mini-parks, planned for the City Centre, might be difficult.	
MBR	-Surrey City Centre is being built in an environmental era and not an industrial area. -What kind of downtown are we going to create in an environmental era? -Downtown in an environmental era will not be all paved (perhaps there will be a swale on every site).	Key idea: Surrey City Centre is being built in an environmental era, not an industrial era
MBR	Should try to bring the Salmon to the City.	
MBR	Likes the following message because it is easy to understand and impactful: "Once the city centre is connected, the health of the watershed is going down."	Key idea: Increased connection of city centre to drainage system is <u>directly linked</u> to decrease in watershed health.
NP	There is a physical gap between Quibble Creek and the City Centre. Perhaps City Centre can be connected to the Creek by some physical feature.	
MBR	Re: physically connecting Quibble Creek to City Centre: -The solutions cannot be artificial or for aesthetic purposes only. -The solutions should be based on solid science so that practically speaking there is no other way to achieve the vision and goals. -Recommend realistic and practical solutions.	Key idea: Solutions must be realistic and practical and based on solid science in order to sell them to the public.
MBR	There is a lack of neighbourhood parks in the City Centre but every site has to have some type of open space. On-site source controls could be implemented in these spaces.	
DH	-Developers always say that "they are losing a lot". -Emphasize to them (developers) that all of development has an impact. -Frame the vision in a way that conveys the impact of development and places a certain degree of responsibility on developers for minimizing impact (versus framing it in a way that implies developers are doing bonus work by putting in green features).	Key idea: Emphasize that developers bear <u>responsibility to prevent</u> environmental harm.

Name	Discussion	Outcome/Action
CJ	-Cost Issues? Green Roofs? Purple Pipes? CJ argued that purple pipes are more feasible solutions than green roofs.	
DL	Purple Pipes: -City has not asked developers for purple pipes yet. -City can be bolder (they asked for District Energy and got it). -It is a possibility!	
MBR	The City is taking a phased approach to City Centre development. Right now, the goal is to get development started in the City Centre. As more developers start developing in the area, the City can ask for more from them.	Key idea: Phased development: requirements can be increased over time
MBR	Ask for green roofs for all non-residential developments.	
DH	Few concise goals are better to avoid diluting the message.	Key idea: Vision should be concise and clear
TU	Parks do need better planning for succession – different type of trees, or parkland and riparian, no clear plan for future of park vegetation.	
TU	-Harder to manage trees in residential areas than in dense development. -Succession Planning for riparian areas dominated by deciduous trees → Conservation Strategy	
CB	Vision statement should include flooding (flooding not surcharging).	Goal: Flood protection
	Possible themes for City Centre: Green Downtown, Natures Matters, 2nd Greenest City in the World & Keeping the Salmon in the City.	
CJ	Vision Component? 40 years from now, people can walk to Quibble Creek and see salmon turn.	Goal: Salmon will be present and visible in the creek 40 years from now.
3.0	**Presentation of Issues and Possible Solutions by LM (followed by group discussions)**	
3.1	**Issue 1: Flooding & Network Capacity**	
LM	To address flooding & network capacity issues, KWL will recommend pipe and culvert upgrades based on future condition modelling.	
3.2	**Issue 2: Erosion**	
LM	City has used detention ponds and subsurface detention – what about other options? Tanks? Blue Roof?	
CB	Developers have to limit the discharge rate from their site to meet the regulatory release rate. It is up to them how they achieve this.	BMP option: performance target for detention, with options for achieving target
CB	What level of erosion is OK? Can we reduce erosion in the Creek? Can we improve the flow duration curve? Improve erosion issues and salmon habitat	Goal: Reduce erosion in the creek and improve salmon habitat.
NP	From environmental perspective the erosion happening right now appears to	

Name	Discussion	Outcome/Action
	be naturally occurring – not seeing loss of gravels and streambed.	
CB	Since the creek has a defined corridor, we have to engineer a solution to stop the creek from meandering too much (meandering can have a negative impact on the riparian corridor if it causes loss of trees…).	
MBR	Warning about word choice. Can we say 'bring up to standard' instead of 'improve'?	
CB	Maintain and control rate of erosion.	
DH	Can we improve habitat without cutting back erosion?	
NP	We have to find a balance between allowing excessive erosion and strict erosion prevention that works for the fish. Some of the active erosion sites are also associated with high quality fish habitat (lots of habitat structure)	
SG	City has a gravel replacement program for creeks where habitat gravels have been eroded.	
3.3	**Future Development**	
	Everyone seemed OK with amended topsoil depth of 450 mm on residential as well as commercial properties.	BMP option: 450 mm topsoil can be required for landscaping anywhere.
CB	Rain garden "bulb" (also called bump-out) on roads is OK: -Hide infiltration galleries under them. -Roads staff accept/like this style. -Can be implemented on any street that has parking with the exception of high density downtown areas where you need the width of sidewalk for pedestrians.	BMP option: Bulb rain garden designs can be incorporated in all areas of watershed.
CB	Roadside Rain Gardens: -Nothing is off the table. -Nobody wants to take care of anything in front of their houses anymore.	BMP option: roadside rain gardens may be used if choose locations carefully
DL	Question to KWL team – What density are you assuming outside the downtown core? Question to KWL team - Which is a better infill policy from the hydrological perspective? a) Allowing current re-development trends to continue which usually means larger homes on existing parcels with higher impervious coverage. b) City could encourage "parcelization" by rezoning. City can require a lot more on new/re-zoned parcels. "City can drive redevelopment through the gate of rezoning"	Action: KWL to take a more detailed look at option of re-zoning for infill development (addition to current scope)
DL	We have a shot of improving hydrology in the City Centre with controls and requirements for development. I am worried about the infill area outside the City Centre.	
	Note: possible planning change to existing information - Ice Rinks could be moved to the North of Jim Pattison Outpatient Area	

Name	Discussion	Outcome/Action
CB	KWL can assume that all provincially-owned land will be developed in the future.	
	Private green areas will be developed unless owned by the City.	
3.4	**Water Quality**	
CB	Water Quality Ponds: -For Water Quality, we are implementing source controls like oil and grease separators and bio-swales. Therefore, there is no justification for installing regional water quality facilities unless there are special circumstances. -For example, we might consider a water quality facility, if there is an area that will not be re-developing for a long time and has very poor water quality. -City will evaluate options on a site by site basis. -Ponds are not on the DCC list.	Key idea: City will consider water quality treatment options for specific catchments/concerns
	Utility Corridors: -City likes the idea of using the utility corridors for water quality treatment. -NP mentioned that this idea goes hand in hand with the City's vegetation management plan for restricting woody vegetation within utility ROWs.	BMP option: Use utility corridors for water quality treatment swales
CB	Ditch Retention: -Consider ditches gone in the City Centre. -City has had no luck with simple ditch maintenance. -City prefers the rain garden bulge & tank/infiltration gallery option. -Recommend equivalent ditch requirements for road re-development	Key idea: specifically offset loss of ditches with rain gardens/other treatment options
	Rain gardens on ditch streets with SFR – may be OK -In Panorama Ridge, there is a precedent for "no curb" (CB) -In areas that currently have ditches & are single family residential (not in multi-families) (CB) -CJ mentioned Seattle as an example -Can consider rain gardens in Infill areas (PH)	
3.5	**Green Infrastructure**	
CB	Trailer park will be gone at some point (no timeline) (will become part of the riparian corridor??).	
CB	Green Infrastructure: -Add to the proposed green infrastructure. -Add greenways even if it is not for wildlife connection.	Goal: add to the green infrastructure in watershed
	Riparian Corridor Width: -Is it safe to assume that we are not losing the 30 m corridor? (CJ) -We can maintain 15 m on either side of the creek for most areas since the City owns the land (CB). -In some areas, like the hospital, the City is fighting for 5 m (CB). -Recommend 30 m setbacks: and provide good scientific backing for the recommendation (for example importance of groundwater recharge areas). Provide precedent.	Key idea: recommend full/increased riparian setbacks with justification
4.0	**Other Discussion**	

Name	Discussion	Outcome/Action
CB&DH	Notes on City process and usage of DCC funds: -All DCC goes into a City-wide pool – is not location specific. -City creates 10 year plans every 2 years and allocates money to projects based on priorities. -This makes it key to prioritize ISMP recommendations. -DCC cannot be used to fund rain gardens or green roofs as these are site improvements. -Upfront cost for infrastructure upgrades associated with development is with developer if project is not the City's 10-year project plan.	Key idea: Prioritize ISMP recommendations for capital works
CB&DH	Recommend performance standards for all types of BMPs. Places the onus on developers to find a way to meet the standard that they are comfortable with.	Key idea: Recommend performance standards for developers to meet
CB&DH	City can create incentive for source controls through utility rates.	
CB&DH	Come up with a pitch for purple pipes & City might consider it. There are 2 existing relevant cases: -Hospital has a tank (LEED issue). -City hall has a tank.	
CB&DH	Recommend demonstration projects.	Key idea: Recommend pilot and demonstration projects for specific locations
CB&DH	Examples of STW projects: -Rain Garden on 120 Street (turning right coming into Surrey from Delta) (Deborah Jones) -North Vancouver MEC (KWL) -Abbotsford Permeable Pavers - Guilford Pool (Bing Thom Architects) : dry creek used for retention and infiltration -Park Place, Concord Pacific Development in Surrey -Integrate landscaping with SWM (Hislop/Vander Zalm??)	

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Meeting Notes

MEETING DATE: December 21, 2012 10 am to 12 pm

LOCATION: Surrey City Hall (Parks Planning Room #1)

RE: **QUIBBLE CREEK ISMP**
Surrey City Centre Stormwater Management Opportunities
Our File: 0471.239

ATTENDEES: David Hislop (DH), City of Surrey Engineering
Carrie Barron (CB), City of Surrey Engineering
Mary Beth Rondeau (MR), City of Surrey Planning
Laurel Morgan (LM), KWL
Sara Pour (SP), KWL
Ryan Crago (RC), van der Zalm + associates inc.
Mark van der Zalm (MV), van der Zalm + associates inc
Clarence Nery (CN), Kasian Architecture
David Rose (DR), Pd group
Grant Brumpton (GB), PWL Partnership

DISTRIBUTION: All attendees

INTRODUCTION

The work program for the Quibble ISMP recommends collaboration with a focus group of architects working in the new City Centre to identify practical and effective source control options to maintain interflows and baseflows and flow rate control facilities that are realistic considering the sensitivity of development costs in the City Centre, space constraints and native soil infiltration rates. The additional purpose of discussion was to brainstorm how we can increase use and uptake of source control solutions for stormwater management in a developing urban context such as the Surrey City Centre.

The architects invited to the meeting had experience working in the city of surrey and/or had experience with stormwater management. Some of the projects that the attendees had experience with are listed below:

CB & DR – worked on RCMP Division E Headquarters

CB- was initially part of the City Centre Design Master Planning Process

CB – worked on the City Hall project

GB – working on a development at Fraser and King George

GB – working with BTA on the Guildford Pool and the mall

MV – was involved in the Park Place development

MV & RC – helped develop the Stormwater Calculator

Discussion	Key Points
LM opened the session with an introductory presentation that covered the following topics: • Quibble Creek ISMP: project overview, scope, goals, and vision • Project objectives with regards to Surrey City Centre • Surrey City Centre overview: existing versus future scenarios • An overview of Best Management Practices that are being considered to mitigate impact of development	
Open Discussion: Stormwater BMP Solutions • **Requested feedback on the following topics from meeting attendees:** - **Barriers and opportunities for BMPs** - **Synergies with the architectural design process** • Opportunity: Surface BMPs look aesthetically pleasing and can serve as showcase features.	Surface BMPs' aesthetic qualities make them appealing to developers and architects.
• Opportunity: Quibble creek is a unique creek. Raise awareness of the creek's unique features: wild salmon + riparian area. - Raise awareness so that developers will understand that SW is an important issue in the Quibble Watershed and will hopefully get the civil consultant involved at earlier stages in the project.	Raise awareness about Quibble Creek and its unique environmental values.
- ***Showcase the Physical Creek in the City***. Riparian areas are currently fenced off or hidden. The City will increase access to the areas and will showcase the creek more as neighbourhood quality changes during redevelopment, but likely will not occur quickly.	Showcase the physical creek.
- ***Raise awareness though the ISMP process.*** Use the process to discuss the development risk to the creek with developers/residents/staff. - ***Raise awareness through stories about Quibble Creek.*** Highlight cultural elements of the creek and tell stories about pioneers, first nations, and significance of salmon. Publish the stories on websites, blogs and [internet] hit generators. These stories can serve as design inspiration for the architects and can engage the public.	Tell stories about the creek.
• Green Roofs: - A variety of green roofs types and insurance packages are available in the market. They make it easier to implement green roofs but don't all provide the same stormwater benefit. - Planning would like to encourage the implementation of the green roofs that provide stormwater benefit. - GB: as far as pricing goes, mid-height buildings are best suited for green roofs. High-rise construction is expensive.	

<table>
<tr><th>Discussion</th><th>Key Points</th></tr>
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Retaining native soil on site during construction.

Developers are reluctant to do it due to space issues.
There is a limit on how high the soil can be stock piled both for stability and preservation of the soil structure.

Riparian area setbacks

The architects would prefer not to see hard physical barriers at the edge of the riparian set back
There is opportunity to have planting and landscaping on the site adjacent to the riparian area that is inspired by the riparian area and that extends the riparian area.
Successional planning is recommended – to adapt vegetation to the site over time

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Brainstorming: What Can We Do to Increase Use of Source Control BMPs?

Discussion of the process for designing and incorporating stormwater and source control facilities in a site.
What would make it easier to include BMPs?
How can they be encouraged in general? What pressures produce results? What pressures produce negative reactions?
From the perspective of the architects present at the meeting, the developers, which the architects have as clients, are generally open to the idea of incorporating BMPs on-site. The developers’ primary barrier is cost.

GB suggested that there should be a City requirement for BMPs.
If there is a requirement regarding BMPs that all developers have to meet (level playing field), then the developers will spend the money to meet the requirement.
There was a suggestion that if the City does establish stormwater management requirements, they should not be overly prescriptive but rather criteria that the developers can achieve in different ways.

Another barrier to incorporating BMPs into site design is space issues.

Surrey’s tree planting requirements are stringent and strictly enforced. The trees and the surface BMPs are competing for the same space on the development site.
Can these competing requirements be reconciled? Green space that is part of maintained BMPs can count instead of

</td><td>
Developers in Surrey City Centre are open to the idea of BMPs.

Cost of BMPs and space requirements for BMPs are barriers to wide spread use of BMPs by City Centre developers.

There is a need for a City enforced stormwater management requirement.

Is there an opportunity for streamlining parks (tree planting) and engineering (stormwater) requirements?
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Discussion	Key Points
trees or tree planting can be incorporated into BMPs? - Can stormwater benefits provided from tree planting be assessed and accounted? - Is there a way to assess the cost/benefit of tree planting and cost/benefit of on-site stormwater infiltration and require whichever provides the most benefit for the Quibble watershed? Trade-offs? Synergies?	Is there need for a policy?
• It was iterated several times that there is disconnect between engineering and park department. Randall Epp, from Planning & Development, was mentioned several times. - Can a policy be adopted to streamline requirements of both departments so that they are not competing?	
• Stormwater Calculator: useful tool? - The calculator is a simple tool developed by DH and Van der Zalm that quantifies the benefits of some on-site BMPs. - DH: "calculator says dirt = detention". The point of the calculator is to show that the cumulative impact of small on-site measures is significant. - Benefits of tree canopy can be added to the SW calculator based on Richard Boase's research. - Refine the tool so it can be used by every consultant.	A stormwater calculator similar to the one discussed would be a useful tool for architects and other consultants.
• LEED certification? - LEED is considered at early stages of every project - People in the development community go for it because they know that they don't have to go above and beyond what they typically do to get their buildings certified - "It is a blunt instrument" – let's move past it	
• From the perspective of planning department (MR), stormwater always ends up at the bottom of the list of priorities when it comes to development. Fish are important in all Surrey stream and not only Quibble Creek. What can practically and realistically be done to increase implementation of BMPs? - MV- positive reinforcement from planning room versus mandating bylaws - Including civil engineers on the advisory design panel (ADP) - Allow for site specific strategies based on watershed health needs and site constraints (sometimes an entire parking lot with permeable pavers makes sense and sometimes a tank makes more sense) - Stormwater issues should be presented at early stages in a	There is a need for a SWM requirement that each developer has to meet at the edge of the development property. The requirement should be transparent and based on science. The criteria should not be overly prescriptive.

Discussion	Key Points

development project (because after initial planning meetings and once the streamlined design process gets going, it will be hard to introduce new ideas into the project).
- According to DR, stormwater management issues are not in planning documents and bylaws. Include SWM concerns in planning documents. Raise awareness of the reasons for requirements for stormwater management.
- Set a requirement for stormwater that developers need to meet at the edge of the property. Offer a suite of options that developers can use to meet the requirements. Any bylaws and regulations should be transparent and any requirements should be based on science and numbers.
  - How would this be implemented?
  - Use the stormwater calculator to determine the deficit of treatment on site
  - Pick BMPs from the suite of choices to treat the deficit
  - Make proof of meeting the stormwater criteria a requirement for development permit (and part of the development application).
- The tree planting policy was used as an example. GB mentioned that the bare requirement of 'they have to plant trees' is very effective. How about volume capture?
	Stormwater issues should be presented at early stages in the design process and in planning documents and bylaws.

• From the perspective of the planning department, lack of requirement is paralysing. Without a requirement, the 'good developers' end up doing a lot more than the other developers. The planning department does not want to penalize the 'good developers' and therefor does not ask them to do significantly more than the other developers. • Look at Portland for examples of BMPs in action. They are leaders in LID and have good resources available.	
• Incentives - The following question was posed. Does the City save infrastructure spending money when developers implement BMPs? Can the City provide some type of financial incentive for the developers? - Engineering Perspective: Surrey has already saved developers money by not forcing them to buy land for detention and by keeping the DCCs low. Instead of acquiring	Architects were in favour of incentives but the planning department does not believe that incentives and 'bonusing' are beneficial. Currently, Engineering does not have an incentive to offer.

Discussion	Key Points
land to build large regional detention facilities, Surrey is trying to treat stormwater through decentralized, on-site measures. - Planning Perspective: incentives do not work. From a regulatory perspective, incentives are a 'loser' from the beginning. City gets stuck with them years later, can't go back. Example made to the density give-away (bonusing) in the City Centre decades ago tried to encourage development but created lingering problems for City and re-development. • Continuing this workshop and creating other opportunities for learning and collaboration can increase awareness of stormwater issues and implementation of BMPs. Everyone Agreed! • Including Civil Engineers earlier in the design process - Architects do not go to the civil consultants looking for opportunities. They only go to the civil consultants when they have problems. - There needs to be a shift in culture so civil consultants are part of the original team, original design goals. - As it is, civil often does not get involved until after the development permit is obtained - Integrative site planning? Could this be a City requirement?	Continuing collaborative workshops where engineers, planners, architects, and City staff can share ideas and best practices will be beneficial. Civil Engineers should be involved in development projects at earlier stages. They can identify opportunities and barriers for stormwater management early on. This can be a requirement by the City.
Open Discussion: Examples of Successful BMP Implementation • RCMP Headquarters: - Stormwater management was part of the design process from the initial stages of the project. Architects were aware of the issue. - Tried to incorporate bioswales and permeable pavers but they were rejected based on cost-benefit. - Included a pond which serves as a stormwater detention pond, permanent aesthetically pleasing water feature, and irrigation water for green roofs - It difficult to incorporate BMPs due to the tree planting requirements. • Surrey Civic Centre: Quibble Creek was not a driver • Park Place Towers: BMPs are implemented and the stormwater calculator showed that no additional detention is required. • Guildford Mall: the detention facility is lined (no infiltration) because of poor soils and proximity of the pond to the building foundation	

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Appendix G

Application of Source Controls

Appendix G – Application of Source Controls

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G Mitigation Measures

G.1 Low Impact Development Practices

Introduction

Low Impact Development (LID) is a design with nature approach that reduces a development's ecological footprint. LID concepts embodied at the planning stage, often affords more opportunities to reduce the overall negative effects of development and reduce costs. Requirements for expensive traditional stormwater infrastructure may also be reduced as less runoff will be generated.

There are many best management practices (BMPs) commonly used in LID, however it is not always possible to incorporate all of them into a development, and even with adoption of all available LID options, there will still be changes to the hydrologic regime relative to the pre-development conditions and some additional measures or facilities will often be required. LID practices are most effective in mitigating adverse stormwater effects when used in combination with other BMPs, such as constructed source controls and detention. The *Puget Sound Action Team's LID Technical Guidance Manual*[1] is an excellent resource for LID planning and design.

Reduced Road Widths

Traditional road pavement widths may be larger than they need to be, particularly for streets that are residential access only, and not thoroughfares. Road widths can be narrowed to a minimum that allows necessary traffic flow, but that discourages excess traffic and excess speed, both of which are beneficial in a family- and pedestrian-oriented neighbourhood. Road widths do, however, need to meet the community's needs for utility and emergency vehicle access and these requirements will often determine acceptable minimum road widths.

Reduced Building Footprints

Building footprints, and impervious roof area, may be reduced without compromising floor area by increasing building height. This also allows greater flexibility to develop layouts that preserve naturally vegetated areas and provide space for infiltration facilities. Some relaxation of building height restrictions may be necessary to allow this type of design.

Reduced Parking Standards

Reducing the required number of parking spaces for a development reduces the impervious area and encourages pedestrian and public transit-friendly communities. Reducing the required parking spaces also reduces development costs.

[1] Low-Impact Development Technical Guidance Manual Puget Sound, 2005. http://www.psparchives.com/our_work/stormwater/lid.htm

Appendix G – Application of Source Controls

Limiting Surface Parking

Limiting surface parking and restricting parking to below building roof areas, also directly reduces the impervious area in a development.

Pervious Parking Surfaces

Use of pervious paving materials rather than impervious concrete or asphalt can reduce the runoff generated from parking areas. Pervious materials may include pavers, reinforced clean crushed gravel, reinforced turf, or engineered permeable pavements.

Reinforced Clean Crushed Gravel

Geogrid

Building Compact Communities

A complete and compact development plan preserves more natural watershed features and significantly reduces imperviousness. In some cases, compact communities have up to 75% less roadway pavement per dwelling unit, and parking needs are reduced because local services are more accessible by pedestrians and via public transit.

Preserving Naturally Significant Features

Preservation of natural areas in a watershed is always an important consideration, which can provide recreational as well as environmental benefits but some natural areas perform special aquatic ecosystem functions and as such are vital to maintaining watershed health. These areas, which include riparian forests, wetlands, floodplains and natural infiltration depressions with highly permeable soils, are particularly important to inventory and protect from alteration.

Appendix G – Application of Source Controls

G.2 Stormwater Source Control Technologies

Stormwater source controls reduce the runoff that is discharged to the stream network by managing the water balance at the site level. Source controls play a key role in achieving Rainwater Management Criteria for volume reduction, water quality treatment, and runoff control and can be very effective at reducing runoff volumes and peak runoff rates from events smaller than the 50% of 2-year storm. Though they do provide some flow-detention benefits for the 2-year storms, source controls have limited ability to reduce peak runoff rates from large storms and must be designed with adequate overflow capacity. Additional stormwater infrastructure must be provided to safely convey stormwater offsite for the larger events.

Several standard source control technologies are described below. The *Metro Vancouver Stormwater Source Control Design Guidelines*[2] is an excellent reference for source control BMP design advice.

Absorbent Landscaping

Natural topsoil is generally permeable. The vegetation on topsoil provides a layer of organic matter which is mixed into the soil by worms and micro-organisms, creating voids, which allow rain water to percolate through, and making the soil more structurally capable of providing storage in the void spaces when saturated.

Standard construction practice is often to strip the existing topsoil, compact or excavate a site surface to the desired grade, and then cover it with a thin layer of imported topsoil. Although lawns and other ornamental landscaping will establish a vegetated surface, both the original surface and subsurface flows and storage capacities have been altered and surface runoff will be increased. Instead of stripping and removing, original topsoil it should be replaced on the site and augmented with organic matter and sand to improve soil structure and increase macropore development.

To increase absorbency, surface soils should have a minimum organic content to facilitate plant growth and a soil depth sufficient to meet the 50% of 2-year rainfall capture target. Increased soil depths also provide retention for runoff from adjacent hard surfaces. Surface vegetation should include herbaceous groundcovers with a thickly matted rooting zone, deciduous trees, or evergreens.

Some maintenance over the long term is required for the absorbent landscape to continue to provide stormwater benefits. Maintenance activities may include replacing soils that have eroded and replanting dead or dying vegetation.

2 Metro Vancouver, Stormwater Source Control Design Guidelines, 2012, http://www.metrovancouver.org/services/wastewater/sources/Pages/StormwaterManagement.aspx

Appendix G – Application of Source Controls

Absorbent Landscaping

Absorbent Landscaping

Surface Infiltration Facilities

Rainfall runoff is stored at or near the surface in a layer of absorbent soil, sand, gravel, or rock, and/or on the ground surface in a ponding area. The stored runoff that infiltrates into the soil becomes interflow and augments groundwater in the sub-surface.

Surface infiltration facilities can look like normal vegetated swales or ponds, and can be aesthetically landscaped and integrated into the design of open spaces. They include bioretention facilities and rain gardens. Both surface and sub-surface infiltration facilities can be effective at the lot level, as well as at the neighbourhood level, where individual lot sizes or layouts don't support on-lot facilities or where more permeable soils or groundwater recharge areas are located off-site. Surface infiltration facilities can, depending on their design, provide some level of water quality treatment as well.

Surface infiltration can be combined with detention, where the detention release rate allows sufficient time for infiltration through the pond. Infiltration facilities are highly dependent on the hydrologic properties of the sub-surface soils.

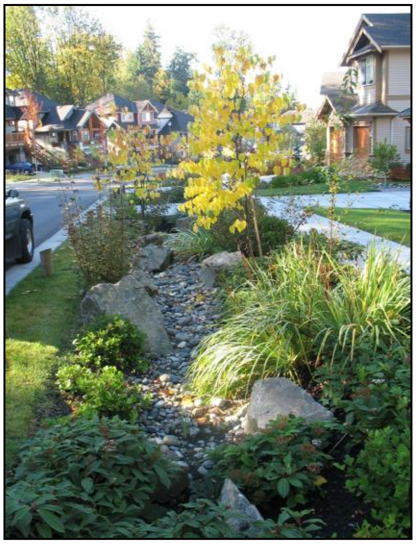
Surface infiltration can also be promoted by the used of permeable pavers or other pervious surfacing materials.

Bio-Retention Facilities

If infiltration rates are low, such as is likely in clay and till soils, bio-retention facilities can be designed to store the volume reduction target in soil and rock trench voids and infiltrate it slowly over time.

Where applicable, a retention facility may also be designed as a baseflow augmentation facility that retains the design capture volume in a tank or pond and releases it at baseflow rates. These rates are very low, and are based on measured summer baseflows in a watercourse divided by the contributing watershed area, and then applied to the area of the site contributing runoff. Baseflow augmentation facilities discharge the capture volume to the downstream stormwater system or watercourse at a maximum of the determined baseflow rates. Any volumes above the capture volume must be allowed to bypass the baseflow augmentation facility.

Appendix G – Application of Source Controls



Bio-Retention Swale

Bio-Retention Swale

Sub-surface Infiltration Facilities

A similar design process is used for sub-surface infiltration as for surface infiltration facilities. The main advantage of sub-surface facilities is that they often have vertical walls and do not require as much dedicated ground area, allowing them to be located beneath paved impervious areas.

Sub-surface facilities must be located at least 0.5 m above the level of the water table so that they can discharge through the sides and bottom of the structure and will not merely store infiltrated groundwater. Generally, the deeper an infiltration facility is located, the less-effective it will be. Subsurface infiltration facilities can be as simple as a trench filled with clean, free-draining rock that is protected from soil by a permeable membrane. There are numerous products available commercially for subsurface infiltration as well.

Sub-Surface Infiltration

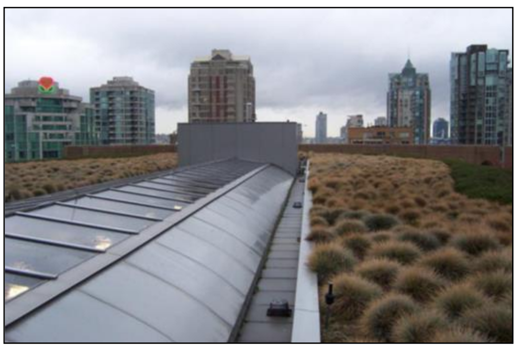
Green Roofs

Installing a green roof rather than a conventional impervious roof can significantly reduce the volume and rate of runoff from a building lot particularly for the smaller, more frequent storm events.

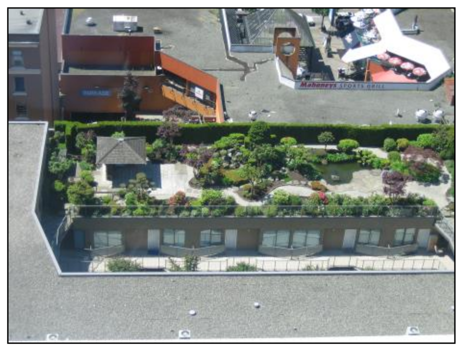
A green roof is essentially a roof with a layer of absorbent soil and vegetation on top of a drainage collection layer or system. Rainfall is absorbed or stored by the soil and vegetation for later evapotranspiration. The green roof has a limited storage capacity, so any excess rainfall percolates through and is collected by a drainage system. The excess rainfall is then routed to the ground for detention and conveyance.

Appendix G – Application of Source Controls

Green roofs are more expensive to build as they have structural costs as well as landscaping costs and do require maintenance to ensure their ongoing functionality. However, when compared with land costs for alternate facilities in high density urban areas, the costs for a green roof may be favourable. Green roofs also have other benefits, in addition to stormwater benefits, that can include heating or cooling cost savings by insulating the building, aesthetic benefits, air quality benefits, and reduced solar gain that decreases the urban heat island effect. Green roofs should only be designed and constructed by qualified professionals as structural engineering, building envelope and landscape design as well as stormwater engineering are all critical components. Green roofs are the preferable source control in areas where ground surface controls are not possible. For more information on green roofs readers are referred to the *Green Roofs for Healthy Cities* website.



Green Roof

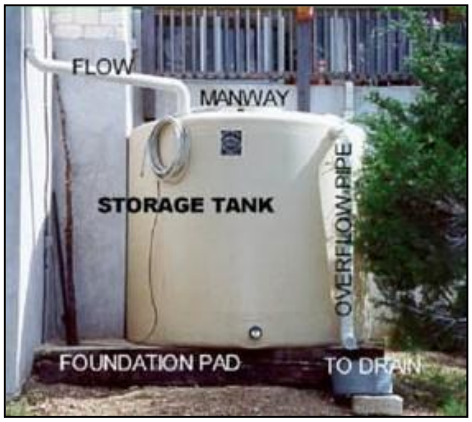


Green Roof

Rainwater Re-use

Rainwater re-use is commonly afforded by residential rain barrels which are effectively retention facilities for roof runoff. Limitations of rain barrels are that rainfall is seldom a reliable source for water during the dryer seasons and rain barrels are often not large enough to store the 50% of 2-year capture target. The most significant reductions in runoff volume from re-use are achieved by capturing and re-using rainwater for indoor grey-water uses, or for commercial and industrial applications with high water consumption rates or where water supplies are limited. Recycling rainwater reduces demands from surface waters and reservoirs and can reduce supply infrastructure costs. Rainwater re-use can also be combined with infiltration facilities.

Appendix G – Application of Source Controls



Re-Use Tank

Re-Use Rain Barrel

Water Quality Best Management Practices

Changes in land use, loss of natural biofiltration capacity, increases in impervious area, and pollutant laden runoff associated with urban development can contribute to reduced water quality which impacts fish and fish habitat. BMPs designed to capture and treat runoff need to be incorporated into RWMPs.

Water Quality BMPs are physical, structural or management practices that reduce or prevent water quality degradation. Many of these are the same as, or similar to those used for runoff volume reduction and rate control and but have ancillary benefits for water quality. Source control remains the key means of reducing introduction of toxic and hazardous materials or organic and inorganic contaminants, originating from land and water use or as a result of commercial or industrial spills. Without source control, runoff water quality is limited by the effectiveness of treatment technology.

Treatment controls are point-source water quality management measures. They are generally constructed facilities and are often individual installations incorporated into the stormwater management infrastructure. They should be designed on a site-specific basis, after examining all alternative treatment technologies, and selecting the best available options based on cost and effectiveness. These controls should be designed and constructed by appropriately qualified environmental professionals.

Water Quality Best Practical Technologies

Several technologies have the ability to provide both water quality benefits and runoff control. Water quality benefits are derived from contaminant removal mechanisms that use biological and physical processes. Runoff control is accomplished by improving stormwater detention and retention which reduces peak runoff discharge rates and volumes.

Appendix G – Application of Source Controls

Biofilters

Biofilters are vegetated filter strips, swales and rain gardens that remove deleterious substances, notably particulate contaminants, though some combination of physical (e.g.: adsorption) and biological (biodegradation) removal mechanisms. Biofilter technology is suitable for sheet flow runoff, typical of large linear impervious developments like roadways and parking lots.

Urban Forests and Leave Strips

Depending on the extent of tree canopy and ground cover retained, runoff reduction and pollutant removal can be achieved by maintaining natural well functioning urban forested areas. The contaminant removal processes forests and natural vegetation provide include: filtration, adsorption, absorption, and biological uptake and conversion by plant life. Urban forests also provide habitat refuges for many species whose habitats have been fragmented while riparian leave strips along watercourses, provide critical fish and wildlife habitat.

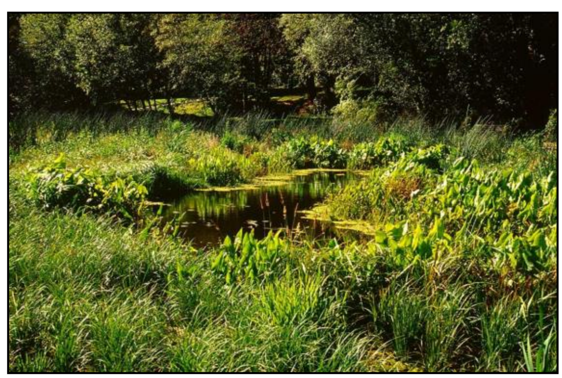
Infiltration Systems

Infiltration systems generally require pre-treatment for water quality to prevent clogging and binding-off of the permeable materials and contamination of underlying aquifers. Physical removal of deleterious substances by filtration and adsorption, as well as conversion of soluble pollutants by bacteria, also occurs within the infiltrating soils.

Constructed Wetlands

Physical, biological and chemical processes combine in wetlands to remove contaminants and either surface or subsurface flow wetlands can be constructed specifically to treat stormwater runoff. Constructed wetlands also offer retention benefits and can create preferred habitats for aquatic and terrestrial wildlife species. **The use of existing natural wetlands to treat stormwater however is not an acceptable practice**.

Small Wetland



Wetland

Appendix G – Application of Source Controls

Wet Detention Ponds

Permanent wet ponds remove pollutants and other deleterious substances through physical processes such as sedimentation, filtration, absorption and adsorption and through biological mechanisms such as: uptake and conversion by plants, and microbial degradation. Wet ponds can also detain flows thereby contributing to rate control and volume reduction objectives. General design parameters need to include: vegetation types (floating, emergent and submergent vegetation), water depth and ponding area, and will often require consideration of detailed pond specific operational parameters.

Oil and Grit Separators

Oil and grit separators are suitable for spill control and removal of floatable petroleum-based contaminants as well as coarse grit and sediment from small areas, such as gas stations, automotive service areas and parking lots. Oil and grit separators have limited application in large-scale stormwater runoff applications, and should be limited to small area generation sites.

Oil Grit Separator

Oil Grit Separator

Construction Best Practices

Construction Best Practices for instream stormwater management works include timing of the works to minimize impacts. Timing windows should be adhered to in order to minimize impacts to fish and wildlife and specifically to avoid sensitive periods for certain life history stages of fish (e.g.; adult spawning, egg and alevin intergravel incubation). Where information is available on critical life history stages and timing for any identified Species at Risk, these times should also be avoided. Clearing should only be undertaken immediately in advance of work, and only during vegetation clearing timing windows, where these have been identified for protection of nesting birds. To the extent possible, work should be restricted to cells and undertaken in a systematic manner to limit the area disturbed at any given time. Works should only be undertaken during favourable weather conditions and low water conditions.

Appendix G – Application of Source Controls

Measures must be taken to prevent the release, from any work site, of silt, sediment, sediment-laden water, raw concrete, concrete leachate, or any other *deleterious substance* into any ditch, watercourse, stream, or storm sewer system. The work area should be isolated from flowing water as much as possible and diversions around the site should be provided for overland flow paths. Ensuring that all equipment used on-site is in good working order, and having a ready spill containment kit and staff trained in its use, are also critical measures.

For further information on managing erosion and sediment discharges during construction, see the Erosion and Sediment Control section of the *Land Development Guidelines and the Standards and Best Practices for Instream Works*.[3]

G.3 Stormwater Detention Systems

The rainwater detention objective is to limit the post-development runoff to the pre-development rate, volume, and approximate shape of the hydrograph for the 50% MAR, and 2-year/24-hour storm events and to maintain, as closely as possible, the natural pre-development flow pattern in the receiving watercourse.

These detention levels have been adopted to address increases in impervious areas in developments and the environmental impacts (e.g. stream erosion, sedimentation; loss of riparian habitat, changes in stream morphology, etc.) that are occurring due to the more frequent, smaller storm events being rapidly conveyed off hard surfaces into fish bearing waters.

G.4 Infiltration Systems

Stormwater infiltration systems can provide many benefits to urban streams. Infiltration systems can retain runoff, recharge groundwater and control peak flows. The soil, through which the stormwater runoff passes, also acts as a filter removing a large percentage of the common pollutants normally discharged to the stream or creek. Infiltration can recharge local groundwater which in turn feeds smaller streams and creeks through seepage. Groundwater which is slowly discharged back into streams and can constitute all or part of a stream's baseflow. This baseflow can be critical for fish and fish habitat during extended periods of little or no precipitation and runoff. It maintains preferred spawning conditions for several salmon species which key on groundwater seepage areas for spawning and egg incubation.

In areas with well-draining soils, stormwater runoff from a site can be collected and discharged into an infiltration system where there are no conventional stormwater removal systems, or infrastructure, which reduces the costs of providing offsite conveyance.

[3] BC Ministry of Water, Land and Air Protection's *Standards and Best Practices for Instream Works* (draft March 2004) http://wlapwww.gov.bc.ca/sry/iswstdsbpsmarch2004.pdf.

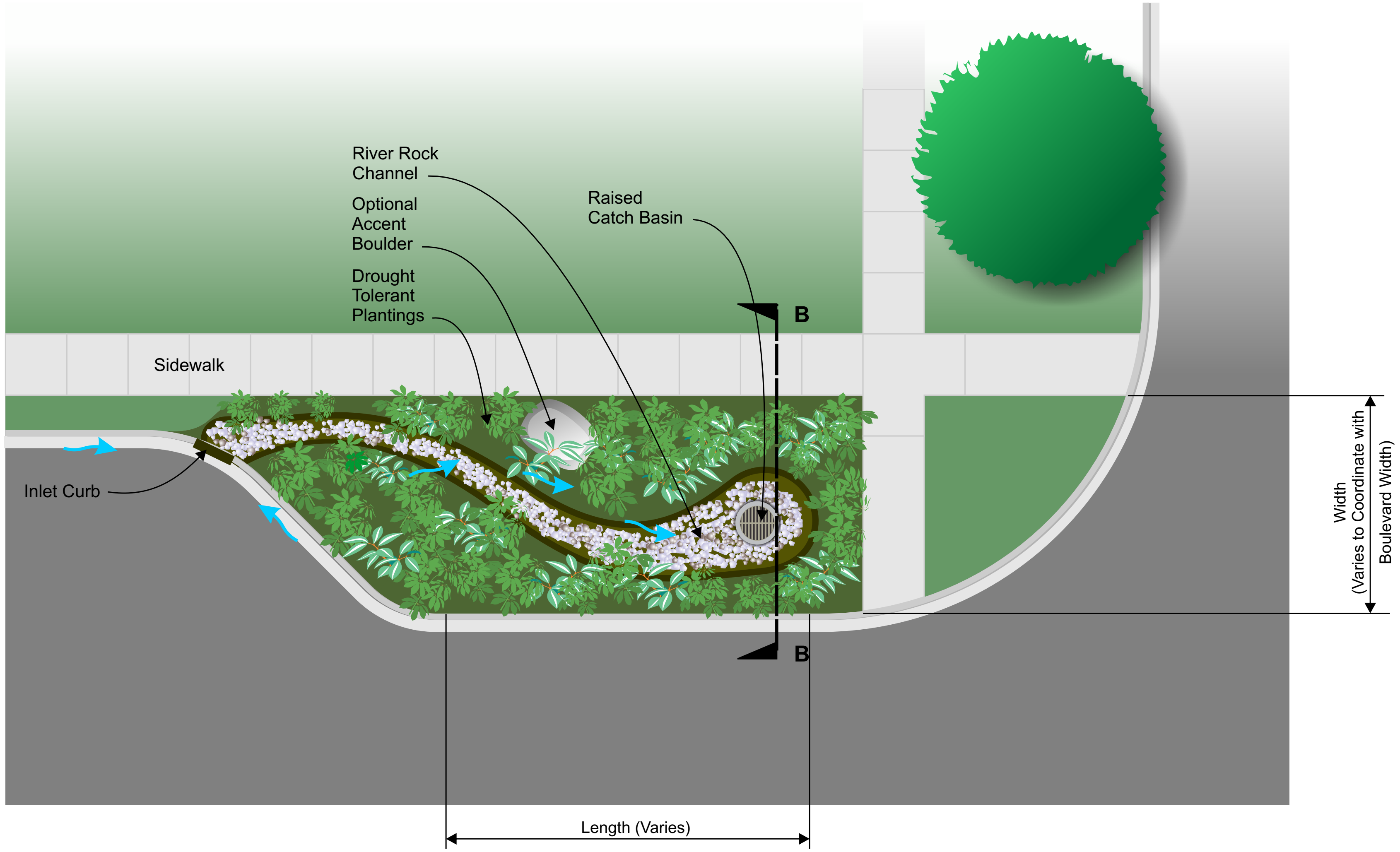
Appendix G – Application of Source Controls

G.5 Roadside Rain Gardens

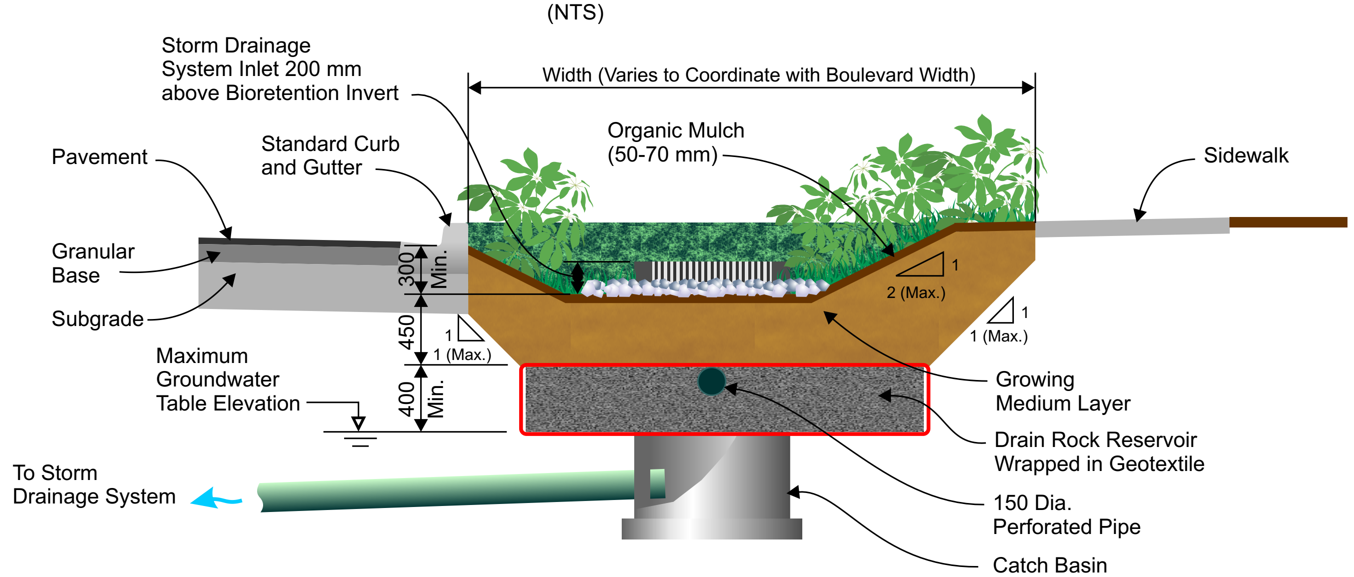
The City wished to further explore the possibility of incorporating rain gardens along the roadways. Preliminary design sketches and guidelines were produced to illustrate how the rain gardens could be situated within the road ROW. Three options were developed:

1. Bump-out rain garden at intersections (see Figure G-1);
2. Bump-out rain gardens mid-block (see Figure G-2); and
3. Modular rain garden contained within the boulevard (see Figure G-3).

These roadside rain garden sketches and guidelines were developed with input from City Staff.



Plan
(NTS)



Section B-B
(NTS)

DESIGN PRINCIPLES

- The rain garden area, calculated as length times width, should be 5% of the upstream impervious area that it serves in areas of poor infiltration.
- At point-source inlets, install non-erodable material, sediment cleanout basins, and weir flow spreaders from the forebay to the rain garden.
- Rain garden bottom width - 600mm (min.) to 3000mm (desirable).
- Side slopes - 2:1 maximum, 4:1 preferred for maintenance. Maximum ponded depth - 300mm.
- Draw-down time for maximum ponded volume - 72 hours.
- Treatment soil depth - 450mm; (composition: <30% silt and clay, 8-15% organics, 0-10% gravel, 50-70% sand) minimum infiltration rate of 20mm/hr.
- Surface planting should be primarily evergreen trees, evergreen shrubs, and groundcovers, with planting designs respecting the various soil moisture conditions in the garden. Plantings may include rushes, sedges and grasses as well for erosion control.
- Apply a 50-75mm layer of organic mulch for both erosion control and to maintain infiltration capacity.
- Avoid utility or other crossings of the rain garden. Where utility trenches must be constructed below the garden, install trench dams to avoid infiltration water following the utility trench.
- For large length rain gardens on slopes steeper than 2%, add timber weirs to achieve $\leq$ 2% slope. (Max. drop per weir is 200mm).
- Planting area for trees adjacent to pavement to use a minimum of 800mm x 800mm x 800mm of structural soil. Exact required quantities will depend on tree selection.

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471-239\500-Drawings\471239_FigG-1_Bioretention.CDR

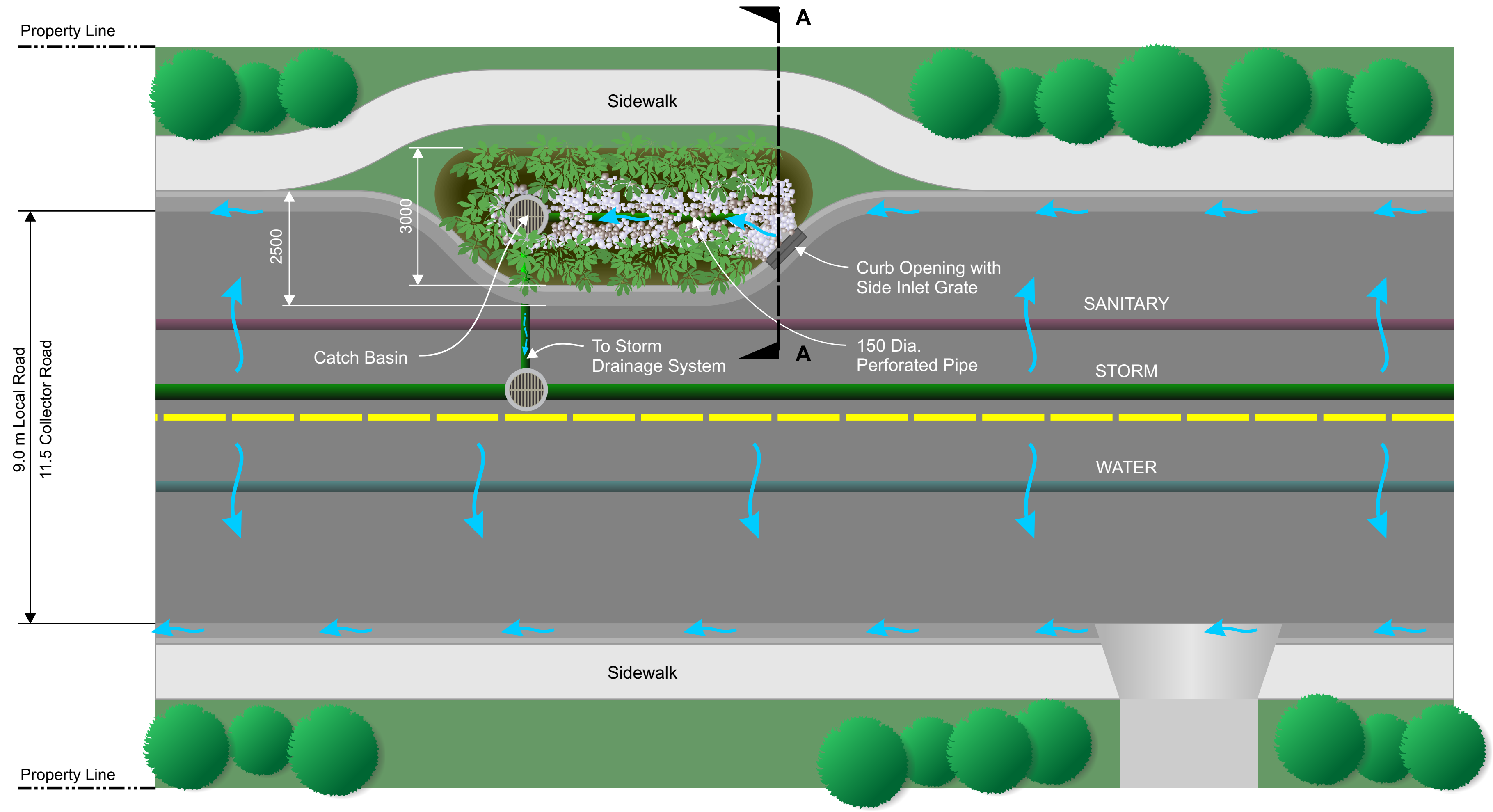
No.	Date	Revision	App'd

Drawn	Date	Checked
JL	2014-02	AK
Scale	N.T.S.	
Approved by		
for City Engineer		

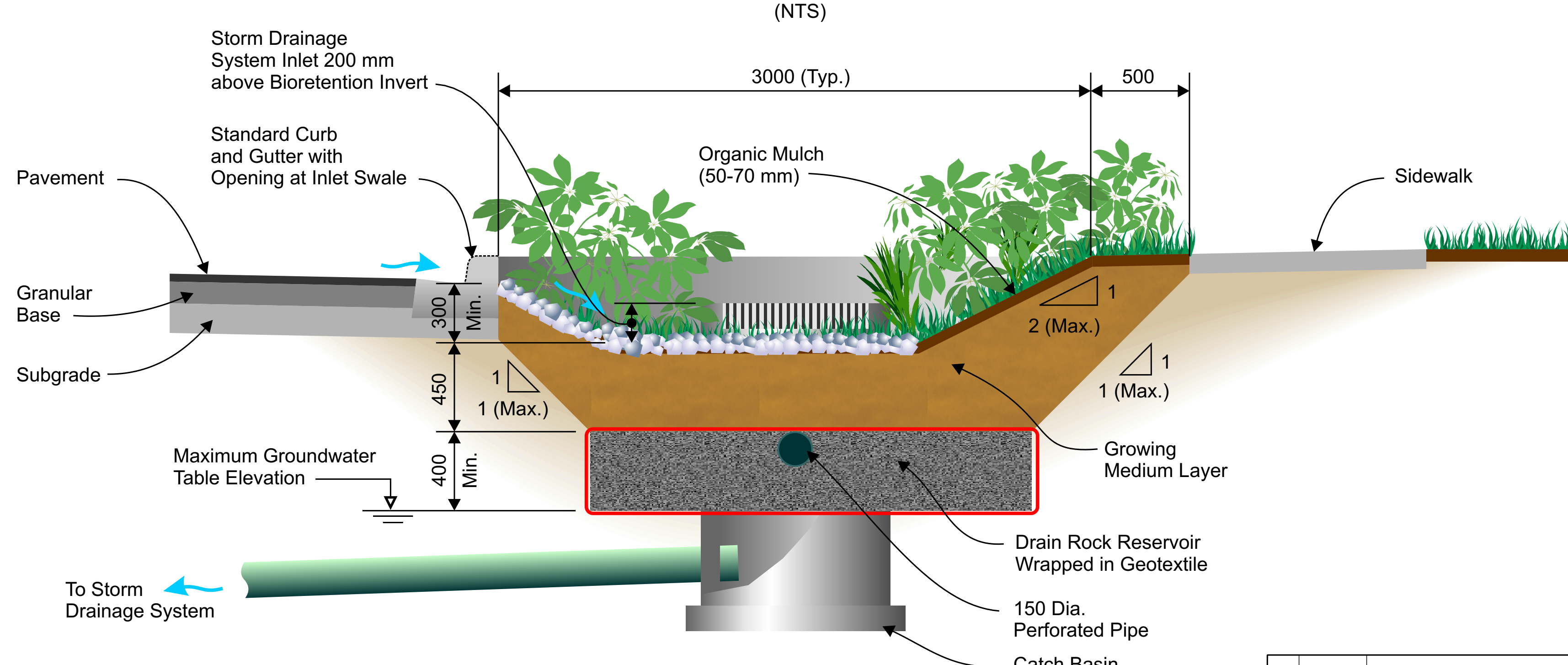
City of Surrey Quibble Creek ISMP

Typical Bump Out Raingarden at Intersection

Sheet
Figure G-1
File Number



Plan
(NTS)



Section A-A
(NTS)

DESIGN PRINCIPLES

- The rain garden area, calculated as length times width, should be 5% of the upstream impervious area that it serves in areas of poor infiltration.
- At point-source inlets, install non-erodable material, sediment cleanout basins, and weir flow spreaders from the forebay to the rain garden.
- Rain garden bottom width - 600mm (min.) to 3000mm (desirable).
- Side slopes - 2:1 maximum, 4:1 preferred for maintenance. Maximum ponded depth - 300mm.
- Draw-down time for maximum ponded volume - 72 hours.
- Treatment soil depth - 450mm; (composition: <30% silt and clay, 8-15% organics, 0-10% gravel, 50-70% sand) minimum infiltration rate of 20mm/hr.
- Surface planting should be primarily evergreen trees, evergreen shrubs, and groundcovers, with planting designs respecting the various soil moisture conditions in the garden. Plantings may include rushes, sedges and grasses as well for erosion control.
- Apply a 50-75mm layer of organic mulch for both erosion control and to maintain infiltration capacity.
- Avoid utility or other crossings of the rain garden. Where utility trenches must be constructed below the garden, install trench dams to avoid infiltration water following the utility trench.
- For large length rain gardens on slopes steeper than 2%, add timber weirs to achieve $\leq$ 2% slope. (Max. drop per weir is 200mm).
- Planting area for trees adjacent to pavement to use a minimum of 800mm x 800mm x 800mm of structural soil. Exact required quantities will depend on tree selection.

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471-239\500-Drawings\471239_FigG-2_Bioretention.CDR

DIMENSIONS ARE MILLIMETRES
UNLESS OTHERWISE NOTED

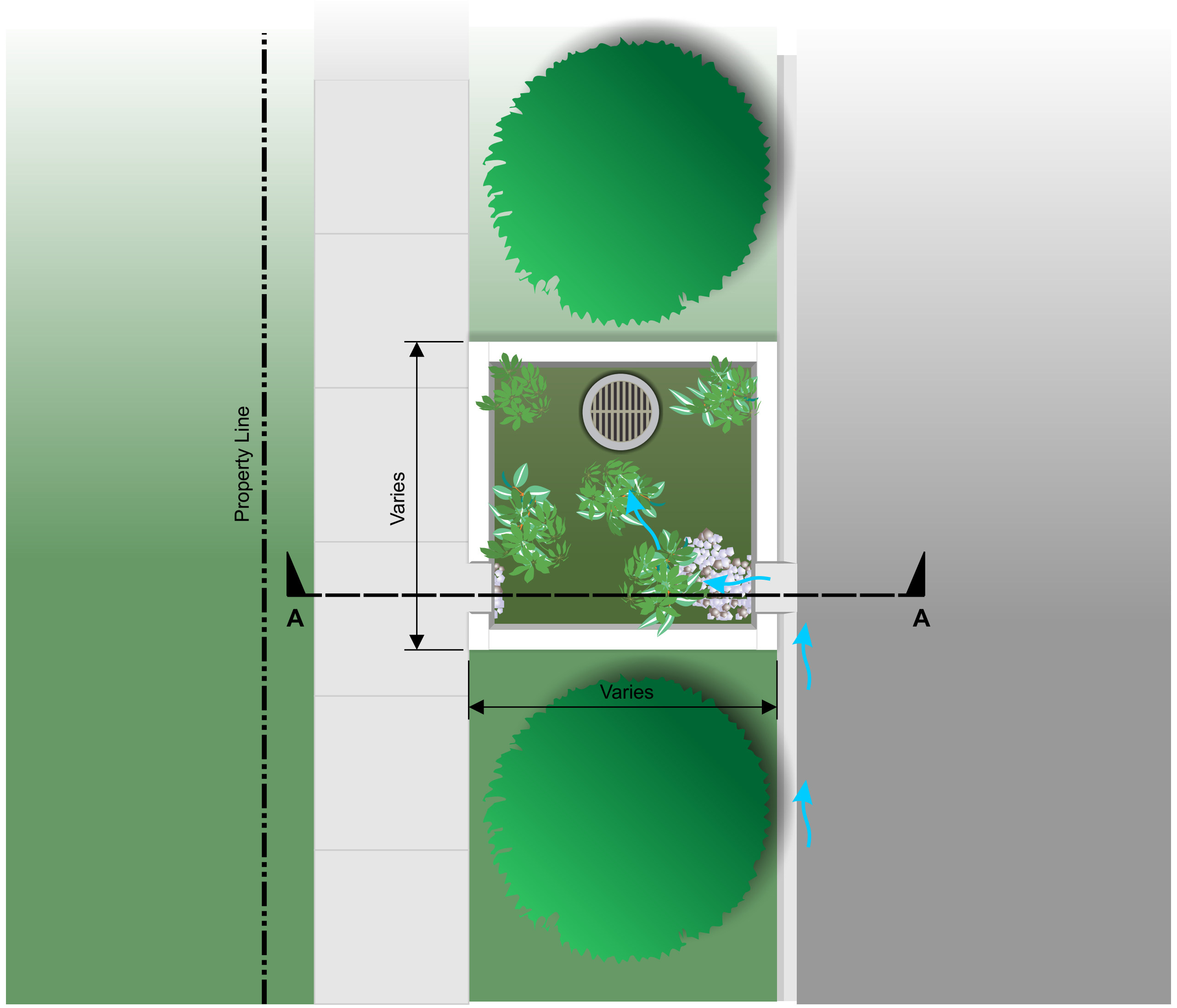
No.	Date	Revision	App'd

Drawn	Date	Checked
JL	2014-02	AK
Scale	N.T.S.	
Approved by		
for City Engineer		

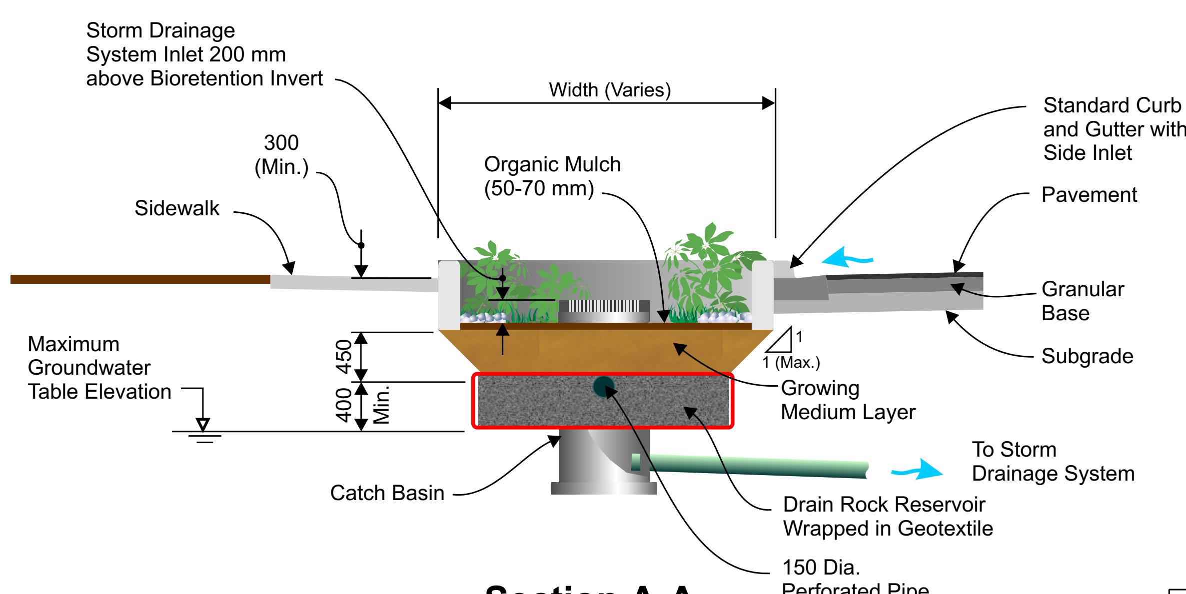
City of Surrey Quibble Creek ISMP

Typical Bump Out Raingarden Mid-Block

Sheet
Figure G-2
File Number



Modular Rain Garden - Plan
(NTS)



Section A-A
(NTS)

DESIGN PRINCIPLES

- The rain garden area, calculated as length times width, should be 5% of the upstream impervious area that it serves in areas of poor infiltration.
- At point-source inlets, install non-erodable material, sediment cleanout basins, and weir flow spreaders from the forebay to the rain garden.
- Rain garden bottom width - 600mm (min.) to 3000mm (desirable).
- Side slopes - 2:1 maximum, 4:1 preferred for maintenance. Maximum ponded depth - 300mm.
- Draw-down time for maximum ponded volume - 72 hours.
- Treatment soil depth - 450mm; (composition: <30% silt and clay, 8-15% organics, 0-10% gravel, 50-70% sand) minimum infiltration rate of 20mm/hr.
- Surface planting should be primarily evergreen trees, evergreen shrubs, and groundcovers, with planting designs respecting the various soil moisture conditions in the garden. Plantings may include rushes, sedges and grasses as well for erosion control.
- Apply a 50-75mm layer of organic mulch for both erosion control and to maintain infiltration capacity.
- Avoid utility or other crossings of the rain garden. Where utility trenches must be constructed below the garden, install trench dams to avoid infiltration water following the utility trench.
- For large length rain gardens on slopes steeper than 2%, add timber weirs to achieve $\leq$ 2% slope. (Max. drop per weir is 200mm).
- Planting area for trees adjacent to pavement to use a minimum of 800mm x 800mm x 800mm of structural soil. Exact required quantities will depend on tree selection.

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No.	Date	Revision	App'd

Drawn	Date	Checked
JL	2014-02	AK

Scale N.T.S.

Approved by

for City Engineer

City of Surrey Quibble Creek ISMP

Typical Modular Raingarden in Boulevard

Sheet

Figure G-3

File Number

471-239\500-Drawings\471239_FigG-3_ModularRainGarden.CDR

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Appendix H

Cost Estimates

Appendix H – Cost Estimates

Contents

Tables

Figures

Appendix H – Cost Estimates

H Drainage System Capital Upgrades Program

H.1 Introduction

Based on the results from the drainage system assessment, this section summarizes the capital upgrades program developed for the Quibble Creek watershed. Criteria for prioritization and cost estimates are included in the following sections.

H.2 Criteria for Prioritization

The upgrades were prioritized by the following criteria:

Priority 1. Based on the existing land use model results, major storm sewers (culverts) that are not sized to meet the 100-year flow and result in flooding on the surface, are sized to meet the 100-year flow as calculated in the future land use model.

Priority 2. Based on the existing land use model results, storm sewer pipes that are not sized to meet the 5-year flow and result in flooding on the surface, are sized to meet the 5-year flow as calculated in the future land use model.

Priority 3. Based on the existing land use model results, storm sewer pipes that are not sized to meet the 5-year flow and result in surcharging above .3 m in height for over 15 minutes, are sized to meet the 5-year flow as calculated in the future land use model.

Priority 4. Based on the future land use model results, major storm sewers (culverts) that are not sized to meet the 100-year flow, are sized to meet the 100-year flow as calculated in the future land use model.

Priority 5. Based on the future land use model results, storm sewer pipes that are not sized to meet the 5-year flow and require two or more incremental pipe diameter increases, are sized to meet the 5-year flow as calculated in the future land use model.

Priority 6. Based on the existing land use model results, storm sewer pipes that are not sized to meet the 5-year flow and require one incremental pipe diameter increase, are sized to meet the 5-year flow as calculated in the future land use model. These are recommended as end of service life upgrades only.

In addition to the pipes that fit the above criteria, the pipes downstream were analyzed and had to be upsized for concerns of potential sewer blockage.

Figure H-1 shows the recommended capital upgrades projects for the Quibble Creek watershed.

Appendix H – Cost Estimates

H.3 Cost Estimate

The cost estimates for the proposed capital upgrades are summarized in Table H-1; grouped by priority. The accuracy of the cost estimates is Class D meaning that the general requirements for upgrading including size and approximate depth of excavation, as well as some general site conditions are known. The projects identified have not considered the following factors affecting construction:

- Relocation of adjacent services (water, hydro, etc.);
- Special permitting requirements (contaminated sites, etc.);
- Geotechnical issues requiring special construction such as pile-supported piping, buoyancy problems or rock blasting; and
- Critical market shortages of materials.

Surveys and more detailed assessments of the proposed capital upgrades should be conducted prior to design and construction.

As the factors above have not been included in the cost estimates, the following allowances are applied to all projects:

- Contractor Markup/Overhead – 6%;
- Market Fluctuation Factor – 15%;
- Bonding/Insurance – 2%;
- Mobilization/Demobilization – 15%;
- Engineering – 20%; and
- Contingency – 40%.

The unit prices reflect KWL's recent experience with similar work, and therefore represent the best prediction of actual (2013) costs as of the date prepared. Actual tendered costs will depend on market conditions, location factors, time of year, contractors' workloads, any perceived risk exposure associated with the work and unknown conditions.

Table H-1 below summarizes the cost estimate for capital upgrades grouped by priority. Tables H-2 to H-7 show the detailed pipe summary, with pipe identification and recommended sizing and associated cost estimate for each priority.

Appendix H – Cost Estimates

Table H-1: Summary of Cost Estimates for Proposed Capital Upgrades

Priority	Cost ($)
1 – Major System, Flooding on Surface, Existing 100-Year Analysis	1,920,000
2 – Minor System, Flooding on Surface, Existing 5-Year Analysis	52,100
3 – Minor System, Surcharge > 15 min and .3 m, Existing 5-Year Analysis	218,800
4 – Major System, Failed Pipe Capacity, Future 100-Year Analysis	208,500
5 – Minor System, Two Incremental Dia. or More Upgrade, Future 5-Year Analysis	875,200
6 – Minor System, One Incremental Dia. Upgrade, Future 5-Year Analysis	1,675,000
Capital Upgrades Program Total $4,948,600	

Appendix H – Cost Estimates

Table H-2: Priority 1 Capital Upgrades

Conduit ID	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
1000762498	5.06	13.72	1,200	3,000	13	27,300	361,000
1000743403	13.09	23.41	1,500	2,400	19	23,500	448,000
KWL_1453	1.92	4.17	750	1,200	34	16,500	567,000
KWL_1454	1.65	4.17	750	1,200	33	16,500	544,000
Priority 1 Subtotal $ 1,920,000							

Notes:

1. Conduits shaded grey above identifies conduits where KWL assumed pipe data such as inverts, slope and/or pipe diameter.

2. These cost estimates are based on City of Surrey's previous project experience. Actual costs may vary depending on unforeseen project design requirements, construction and economic market conditions, local interest in the project(s) and currency fluctuations. These cost estimates must not be construed as guarantee that the projects can be delivered for the estimated price.

Appendix H – Cost Estimates

Table H-3: Priority 2 Capital Upgrades

Conduit ID	Existing 5-Year Flow (m^3/s)	Future 5-Year Flow (m^3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
1000862290	0.07	0.09	200	375	28	380	10,800
1000862293	0.06	0.12	200	375	3	380	1,100
1000752493	0.13	0.19	250	375	34	380	13,000
1000864709	0.13	0.20	250	375	19	380	7,400
1000798043	0.06	0.12	250	375	20	380	7,500
KWL_1444	0.06	0.12	250	375	6	380	2,200
1000769361	0.06	0.12	200	300	21	320	6,800
KWL_1339	0.06	0.12	250	300	10	320	3,300
Priority 2 Subtotal $ 52,100							

Notes:

1. Conduits shaded grey above identifies conduits where KWL assumed pipe data such as inverts, slope and/or pipe diameter.

2. These cost estimates are based on KWL's previous project experience and the level of detail available from the concept plan. Actual costs may vary depending on unforeseen project design requirements, construction and economic market conditions, local interest in the project(s) and currency fluctuations. These cost estimates must not be construed as guarantee that the projects can be delivered for the estimated price.

Appendix H – Cost Estimates

Table H-4: Priority 3 Capital Upgrades

Conduit ID	Existing 5-Year Flow (m^3/s)	Future 5-Year Flow (m^3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
1000758319	0.20	1.10	375	900	12	900	10,800
1000745657	1.25	2.55	750	1,200	21	1,500	31,700
1000758375	0.85	1.45	600	900	31	900	27,800
1001083119	0.07	0.11	300	525	13	500	6,300
1000758140B	0.07	0.16	200	375	57	380	21,500
1000758374	0.85	1.44	600	750	21	700	14,400
1000746169	0.23	0.34	300	450	53	430	22,900
KWL_1352	0.13	0.22	250	375	25	380	9,700
1000758140A	0.06	0.12	200	300	61	320	19,700
1000824112	0.19	0.19	300	375	64	380	24,200
1000824111	0.17	0.17	300	375	79	380	29,800
Priority 3 Subtotal $ 218,800							

Notes:
1. Conduits shaded grey above identifies conduits where KWL assumed pipe data such as inverts, slope and/or pipe diameter.

2. These cost estimates are based on KWL's previous project experience and the level of detail available from the concept plan. Actual costs may vary depending on unforeseen project design requirements, construction and economic market conditions, local interest in the project(s) and currency fluctuations. These cost estimates must not be construed as guarantee that the projects can be delivered for the estimated price.

Appendix H – Cost Estimates

Table H-5: Priority 4 Capital Upgrades

Conduit ID	Existing 100-Year Flow (m^3/s)	Future 100-Year Flow (m^3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
1000762497	9.43	31.08	2,000	4,000	10	12,240*	120,600
1000746272	2.07	2.95	1,050	1,350	34	1,800	60,600
1000765058	0.59	1.08	900	1,050	21	1,300	27,300
Priority 4 Subtotal $ 208,500							

Notes:

1. Conduits shaded grey above identifies conduits where KWL assumed pipe data such as inverts, slope and/or pipe diameter.

2. Unit rates marked with a * above, are calculated as being double barreled culverts.

3. These cost estimates are based on KWL's previous project experience and the level of detail available from the concept plan. Actual costs may vary depending on unforeseen project design requirements, construction and economic market conditions, local interest in the project(s) and currency fluctuations. These cost estimates must not be construed as guarantee that the projects can be delivered for the estimated price.

Appendix H – Cost Estimates

Table H-6: Priority 5 Capital Upgrades

Conduit ID	Existing 5-Year Flow (m^3/s)	Future 5-Year Flow (m^3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
1000743277	61,500	8.70	1,200	2,700	7	9,000	61,500
1000767201	41,500	1.81	1,200	1,950	10	4,050	41,500
1000769409	1,700	1.19	450	750	2	700	1,700
1000752394	68,700	0.73	450	750	98	700	68,700
1000746111	40,700	0.13	450	750	58	700	40,700
1000758320	34,600	0.38	375	675	53	650	34,600
1000755919	21,800	0.08	250	525	44	500	21,800
KWL_1445	3,800	0.13	250	525	8	500	3,800
1000758071	5,800	0.16	200	450	13	430	5,800
1000765051	13,500	1.21	600	900	15	900	13,500
1000758331	13,500	2.07	600	900	15	900	13,500
1000758136	11,500	0.81	450	675	18	650	11,500
1000752392	36,700	1.04	450	675	56	650	36,700
1000746258	28,000	0.05	300	525	56	500	28,000
KWL_1355	3,300	0.29	300	525	7	500	3,300
KWL_1356	39,300	0.24	300	525	79	500	39,300
1000764585	18,100	0.14	250	450	42	430	18,100
1000755450	23,300	0.11	250	450	54	430	23,300
KWL_1354	2,800	0.16	250	450	7	430	2,800

Appendix H – Cost Estimates

Conduit ID	Existing 5-Year Flow (m^3/s)	Future 5-Year Flow (m^3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
KWL_LINK_27	20,300	0.15	200	375	53	380	20,300
1000757960	6,600	0.00	75	200	27	240	6,600
1000758139	26,000	0.74	750	1,050	20	1,300	26,000
KWL_1452	15,300	2.52	750	1,050	12	1,300	15,300
1000765081	47,900	0.71	600	750	68	700	47,900
1000758135	18,200	0.70	525	675	28	650	18,200
1000758134	14,400	0.47	450	600	24	600	14,400
1000758424	27,900	0.35	450	600	47	600	27,900
1000758318	57,800	0.32	450	600	96	600	57,800
1000758145	7,300	0.15	300	450	17	430	7,300
1000752395	18,500	0.46	300	450	43	430	18,500
1000758386	37,400	0.22	300	450	87	430	37,400
1000752399	24,700	0.45	300	450	58	430	24,700
1000758242	0.05	0.07	250	375	8	380	3,000
1000768282	0.11	0.33	250	375	6	380	2,300
1000758083	0.03	0.10	250	375	17	380	6,600
1001121975	0.06	0.12	250	375	11	380	4,200
1000755471	0.06	0.16	250	375	73	380	27,700
1000752498	0.03	0.14	250	375	15	380	5,700
KWL_1340	0.07	0.17	250	375	25	380	9,400

Appendix H – Cost Estimates

Conduit ID	Existing 5-Year Flow (m^3/s)	Future 5-Year Flow (m^3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
1000745628	0.06	0.09	250	375	10	380	3,800
KWL_1447	0.07	0.15	250	375	7	380	2,600
KWL_1456	0.05	0.09	250	375	10	380	4,000
KWL_1443	0.05	0.14	250	375	11	380	4,100
KWL_1457	0.05	0.07	250	375	7	380	2,600
1000752489	0.02	0.04	200	300	17	320	5,400
1000758361	0.03	0.04	200	300	4	320	1,400
Priority 5 Subtotal $ 875,200							

Notes:

1. Conduits shaded grey above identifies conduits where KWL assumed pipe data such as inverts, slope and/or pipe diameter.

2. These cost estimates are based on KWL's previous project experience and the level of detail available from the concept plan. Actual costs may vary depending on unforeseen project design requirements, construction and economic market conditions, local interest in the project(s) and currency fluctuations. These cost estimates must not be construed as guarantee that the projects can be delivered for the estimated price.

Appendix H – Cost Estimates

Table H-7: Priority 6 Capital Upgrades

Conduit ID	Existing 5-Year Flow (m^3/s)	Future 5-Year Flow (m^3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
1000758151	0.61	0.76	900	1,050	25	1,300	32,900
1000745268	0.61	0.90	900	1,050	43	1,300	55,700
1000746316	0.46	0.86	900	1,050	114	1,300	148,000
1000758376	1.24	2.06	900	1,050	32	1,300	41,900
1000746297	0.35	0.50	750	900	15	900	13,900
1000746241	1.11	1.75	750	900	76	900	68,600
1000763003	0.36	0.53	750	900	48	900	43,400
1001170198	0.62	1.17	600	675	11	650	7,400
1000765086	0.58	1.13	600	675	22	650	14,200
1000755449	0.23	0.47	600	675	76	650	49,700
1000758420	0.47	0.62	600	675	44	650	28,600
1000758452	0.58	1.13	600	675	80	650	51,800
1000765021	0.48	0.63	600	675	15	650	9,500
1000755453	0.24	0.48	600	675	77	650	49,800
1000758480	0.70	1.26	600	675	51	650	33,000
1000757945	0.14	0.18	525	600	11	600	6,900
1000751876	0.12	0.23	450	525	75	500	37,300
1000758323	0.19	0.25	450	525	46	500	22,900
1000765079	0.55	0.86	450	525	49	500	24,400

Appendix H – Cost Estimates

Conduit ID	Existing 5-Year Flow (m^3/s)	Future 5-Year Flow (m^3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
1000758422	0.37	0.49	450	525	40	500	20,200
1000743316	0.43	0.44	375	450	29	430	12,500
1000758351	0.13	0.17	375	450	52	430	22,400
1000758402	0.14	0.23	375	450	75	430	32,400
1000766448	0.06	0.13	375	450	40	430	17,200
1000752344	0.09	0.18	375	450	104	430	44,700
1000743375	0.06	0.15	300	375	14	380	5,300
1000758148	0.09	0.12	300	375	123	380	46,900
1000767414	0.09	0.12	300	375	11	380	4,300
1000758487	0.08	0.10	300	375	90	380	34,100
1000752548	0.14	0.21	300	375	47	380	18,000
1000752497	0.10	0.20	300	375	111	380	42,200
1000762875	0.06	0.14	300	375	34	380	13,000
1000755972	0.04	0.06	300	375	54	380	20,600
1000758226	0.05	0.07	300	375	27	380	10,400
1000746177	0.24	0.35	300	375	16	380	6,000
1000752466	0.12	0.22	300	375	47	380	17,700
1000755945	0.04	0.06	300	375	81	380	30,800
1000769389	0.07	0.09	300	375	96	380	36,400

Appendix H – Cost Estimates

Conduit ID	Existing 5-Year Flow (m^3/s)	Future 5-Year Flow (m^3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
1000764587	0.07	0.17	300	375	77	380	29,400
1000752488	0.07	0.14	300	375	56	380	21,300
1000743383	0.08	0.26	300	375	2	380	800
1000765075	0.06	0.10	300	375	15	380	5,500
1001083120	0.09	0.21	300	375	4	380	1,400
1000758247	0.05	0.07	300	375	108	380	41,000
1000762854	0.02	0.02	250	300	39	320	12,400
1000752455	0.03	0.03	250	300	13	320	4,300
1000758413	0.04	0.06	250	300	61	320	19,600
1000769401	0.06	0.08	250	300	42	320	13,600
1000743279	0.10	0.13	250	300	53	320	17,100
1000752404	0.05	0.08	250	300	124	320	39,600
1000765041	0.05	0.06	250	300	16	320	5,000
1000752461	0.04	0.05	250	300	41	320	13,300
1000762465	0.04	0.03	250	300	27	320	8,500
1000768213	0.03	0.10	250	300	11	320	3,500
1000755925	0.01	0.01	250	300	12	320	3,900
1000765070	0.07	0.09	250	300	8	320	2,500
1000758404	0.10	0.13	250	300	12	320	3,800

Appendix H – Cost Estimates

Conduit ID	Existing 5-Year Flow (m^3/s)	Future 5-Year Flow (m^3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
1000768283	0.03	0.06	250	300	12	320	3,900
KWL_1446	0.02	0.09	250	300	21	320	6,800
KWL_LINK_20	0.08	0.10	250	300	75	320	24,000
1000755448	0.00	0.07	250	300	22	320	7,000
1000758074	0.02	0.05	250	300	13	320	4,100
1000751879	0.08	0.10	250	300	50	320	15,900
1000755916	0.01	0.05	250	300	72	320	22,900
1000769396	0.05	0.07	200	250	38	280	10,600
1000758381	0.02	0.02	200	250	11	280	3,100
1000862292	0.06	0.10	200	250	39	280	10,800
1000752458	0.02	0.03	200	250	32	280	9,000
1000746310	0.02	0.03	200	250	60	280	16,700
1000746326	0.04	0.06	200	250	44	280	12,400
KWL_1343	0.03	0.04	200	250	76	280	21,200
KWL_1344	0.04	0.05	200	250	5	280	1,500
1000758099	0.48	0.62	600	675	37	650	24,200
1000752345	0.10	0.08	375	450	54	430	23,400

Appendix H – Cost Estimates

Conduit ID	Existing 5-Year Flow (m^3/s)	Future 5-Year Flow (m^3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Est. Cost ($)
1000752401	0.08	0.11	250	300	85	320	27,300
1000743284	0.10	0.13	250	300	24	320	7,800

Priority 6 Subtotal $ 1,675,000

Notes:
1. Conduits shaded grey above identifies conduits where KWL assumed pipe data such as inverts, slope and/or pipe diameter.
2. Conduits shaded green above identify conduits to be upsized for concerns of potential sewer blockage.
3. These cost estimates are based on KWL's previous project experience and the level of detail available from the concept plan. Actual costs may vary depending on unforeseen project design requirements, construction and economic market conditions, local interest in the project(s) and currency fluctuations. These cost estimates must not be construed as guarantee that the projects can be delivered for the estimated price.

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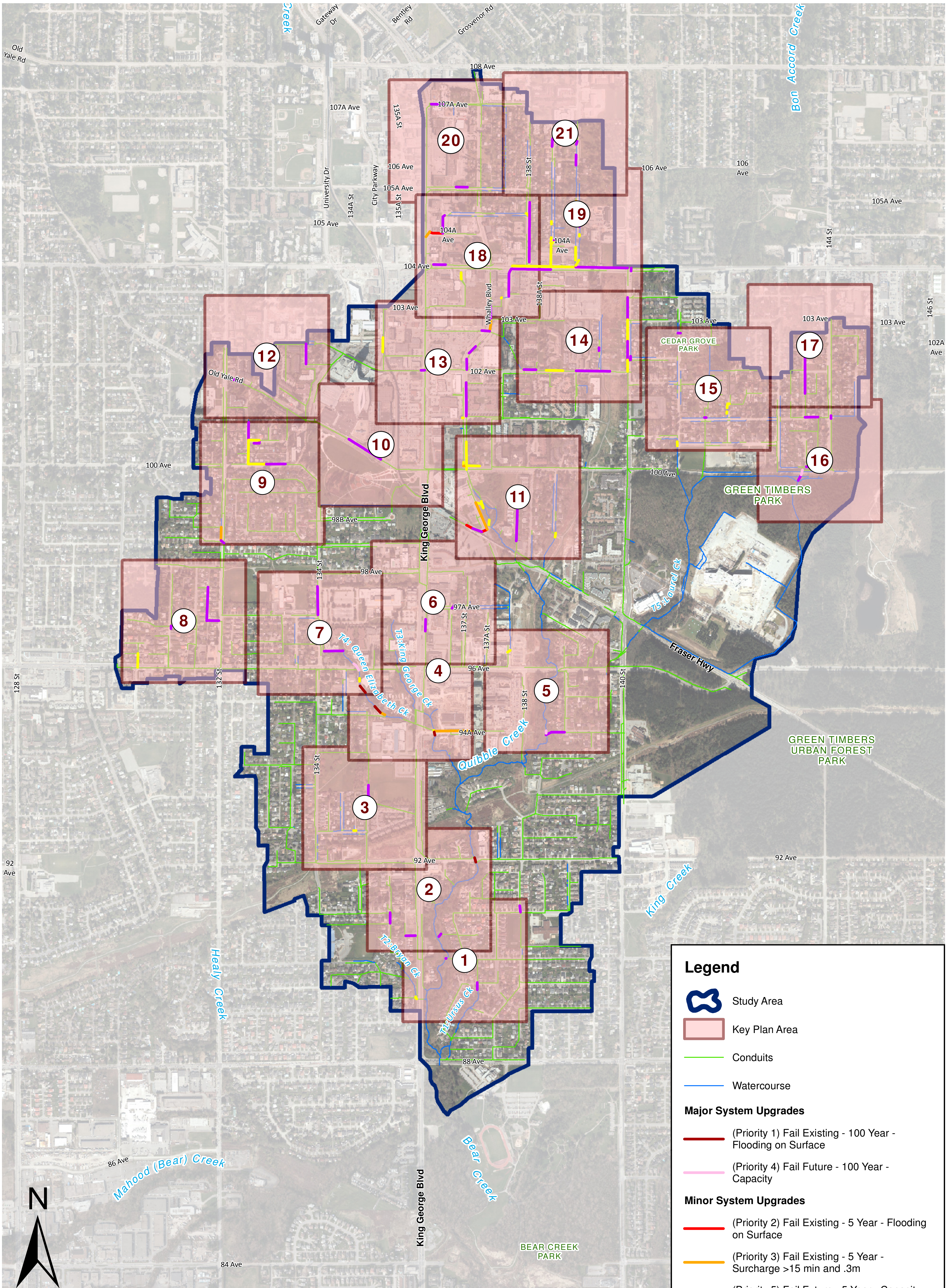

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Quibble Creek Integrated Stormwater Management Plan

Project No.	Date
471-239	February, 2014

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Capital Plan - Priority of Drainage System Improvements Key Plan

Figure H-1

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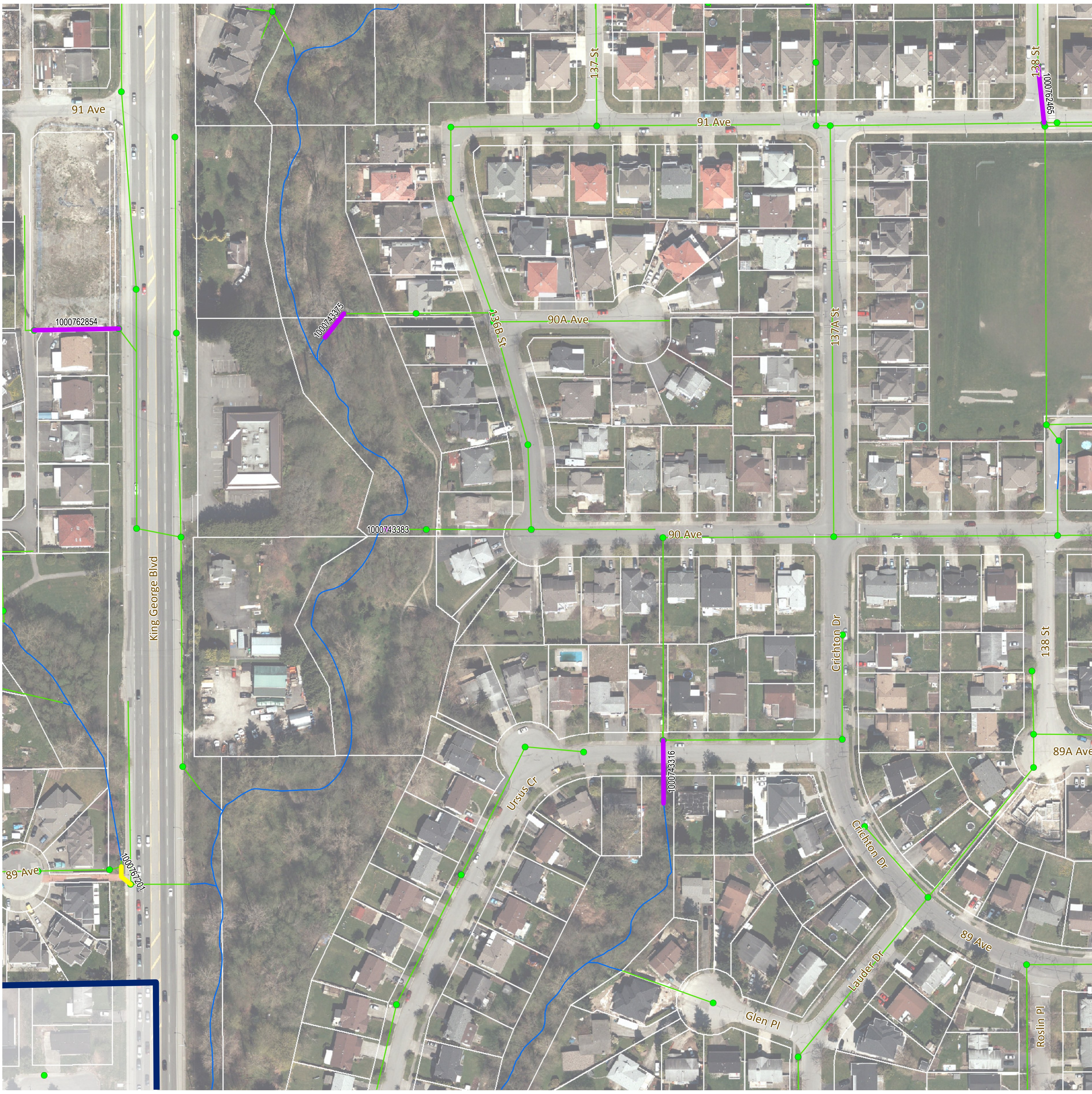

Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000743316	12,453	0.43	0.44	375	450	29	430	6
1000743383	760	0.08	0.26	300	375	2	380	6
1000762465	8,497	0.04	0.03	250	300	27	320	6
1000767201	41,473	1.31	1.81	1200	1950	10	4050	5

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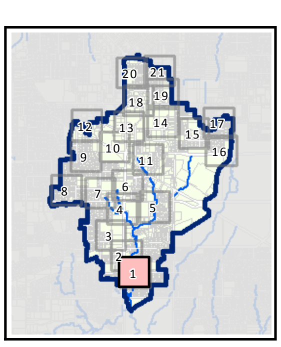

Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Quibble Creek Integrated Stormwater Management Plan

Project No. 471-239

Date February, 2014

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 1

Figure H-2

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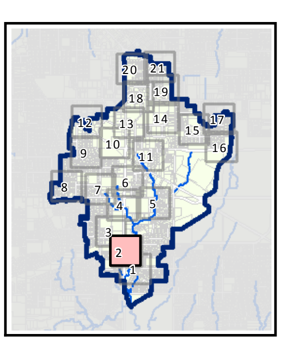
Author: DLee

Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000743375	5,303	0.06	0.15	300	375	14	380	6
1000743403	133,575	13.09	23.41	1500	2400	19	7000	1
1000745268	55,654	0.61	0.90	900	1050	43	1300	6
1000762854	12,409	0.02	0.02	250	300	39	320	6

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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City of Surrey
Quibble Creek Integrated Stormwater Management Plan

Capital Plan - Priority of Drainage System Improvements
Key Plan Area 2

Figure H-3

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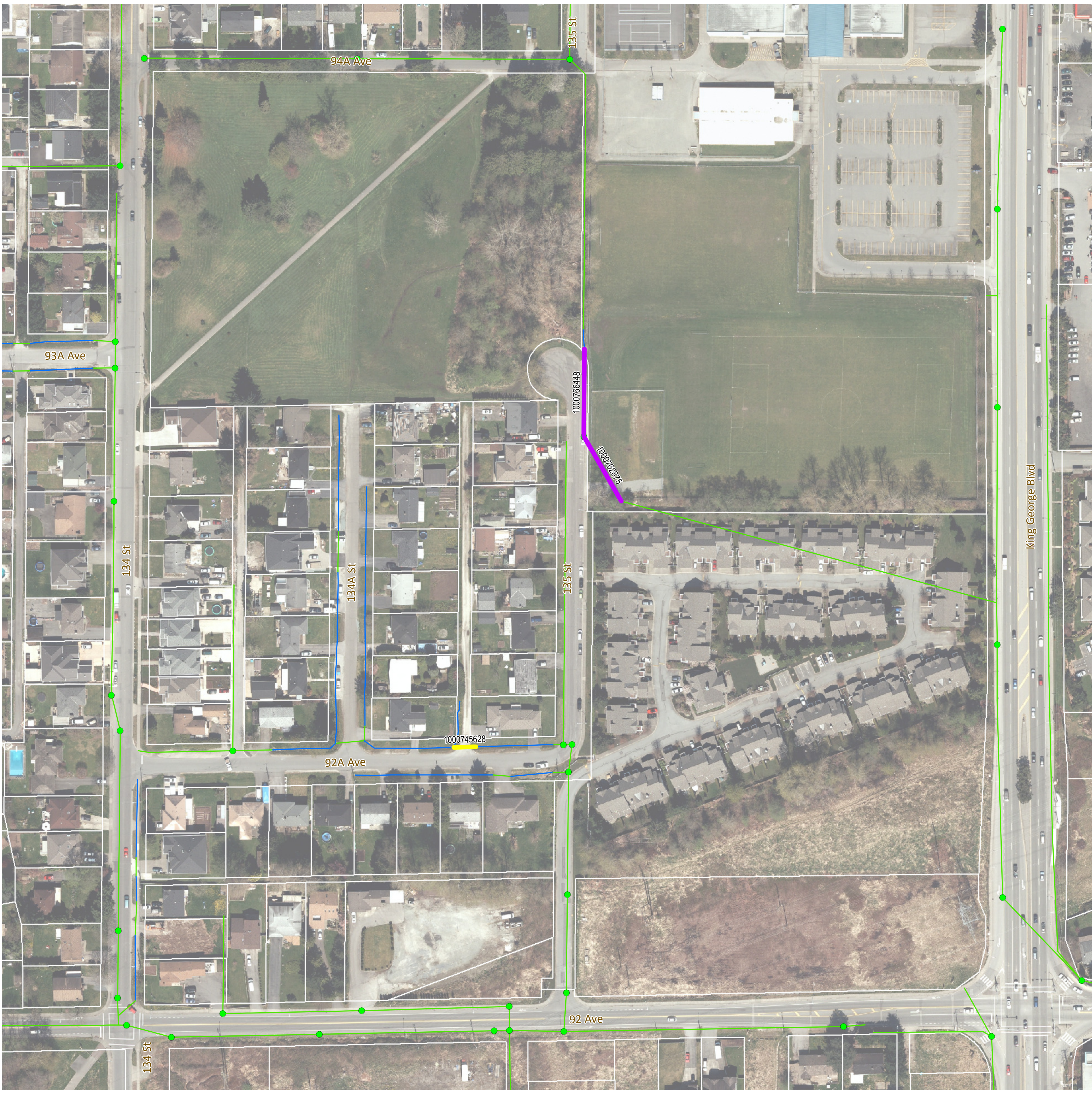
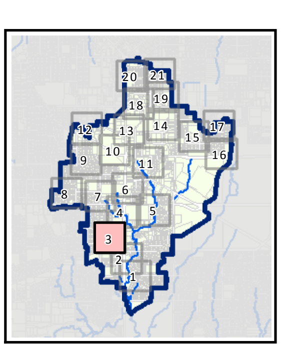


Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000745628	3,847	0.06	0.09	250	375	10	380	5
1000762875	13,017	0.06	0.14	300	375	34	380	6
1000766448	17,200	0.06	0.13	375	450	40	430	6

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

Study Area

Conduits

Watercourse

Major System Upgrades

(Priority 1) Fail Existing - 100 Year - Flooding on Surface

(Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

(Priority 2) Fail Existing - 5 Year - Flooding on Surface

(Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m

(Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required

(Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Quibble Creek Integrated Stormwater Management Plan

Project No.	Date
471-239	February, 2014

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 3

Figure H-4

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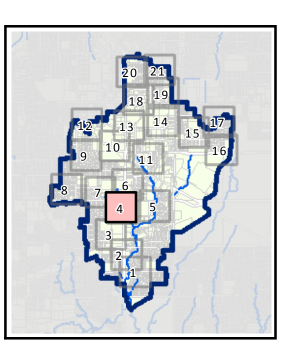
Author: DLee

Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000743277	61,481	3.59	8.70	1200	2700	7	9000	5
1000745657	31,697	1.25	2.55	750	1200	21	1500	3
1000762498	69,807	5.06	13.72	1200	3000	13	5280	1
1000824111	29,845	0.17	0.17	300	375	79	380	3
1000824112	24,154	0.19	0.19	300	375	64	380	3
KWL_1454	49,429	1.65	4.17	750	1200	33	1500	1
1000746272	60,636	2.07	2.95	1050	1350	34	1800	4
KWL_1453	51,543	1.92	4.17	750	1200	34	1500	1
KWL_1452	15,263	1.30	2.52	750	1050	12	1300	5

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

Study Area

Conduits

Watercourse

Major System Upgrades

(Priority 1) Fail Existing - 100 Year - Flooding on Surface

(Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

(Priority 2) Fail Existing - 5 Year - Flooding on Surface

(Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m

(Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required

(Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Quibble Creek Integrated Stormwater Management Plan

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 4

Figure H-5

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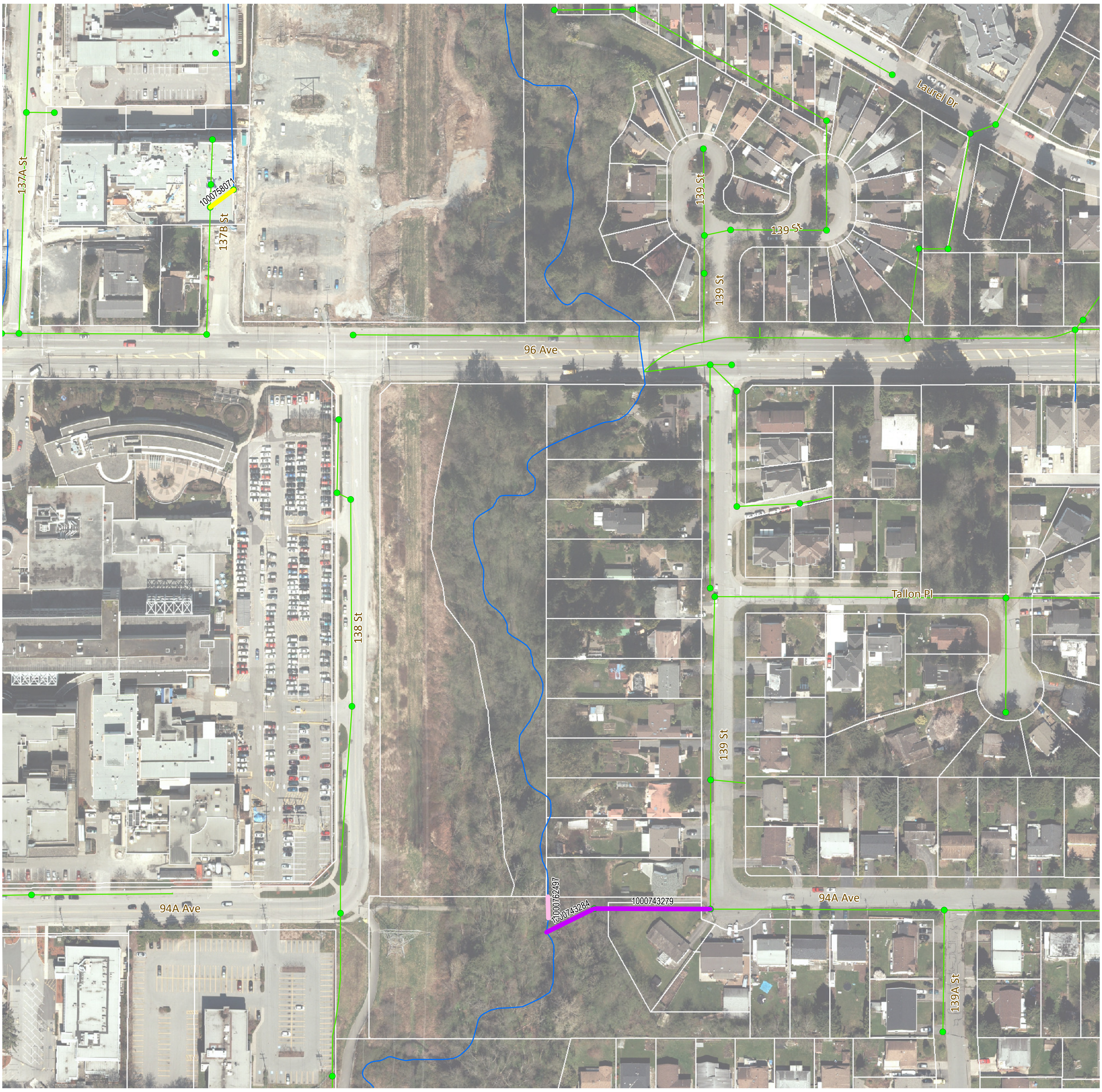
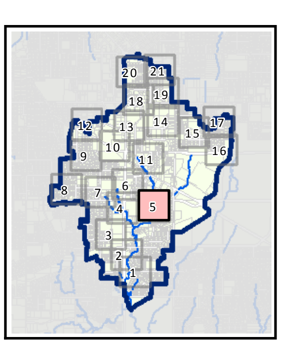


Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000743279	17,066	0.10	0.13	250	300	53	320	6
1000743284	7,802	0.10	0.13	250	300	24	320	6
1000758071	5,785	0.05	0.16	200	450	13	430	5
1000762497	120,598	9.43	31.08	2000	4000	10	12240	4

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Project No. 471-239

Date February, 2014

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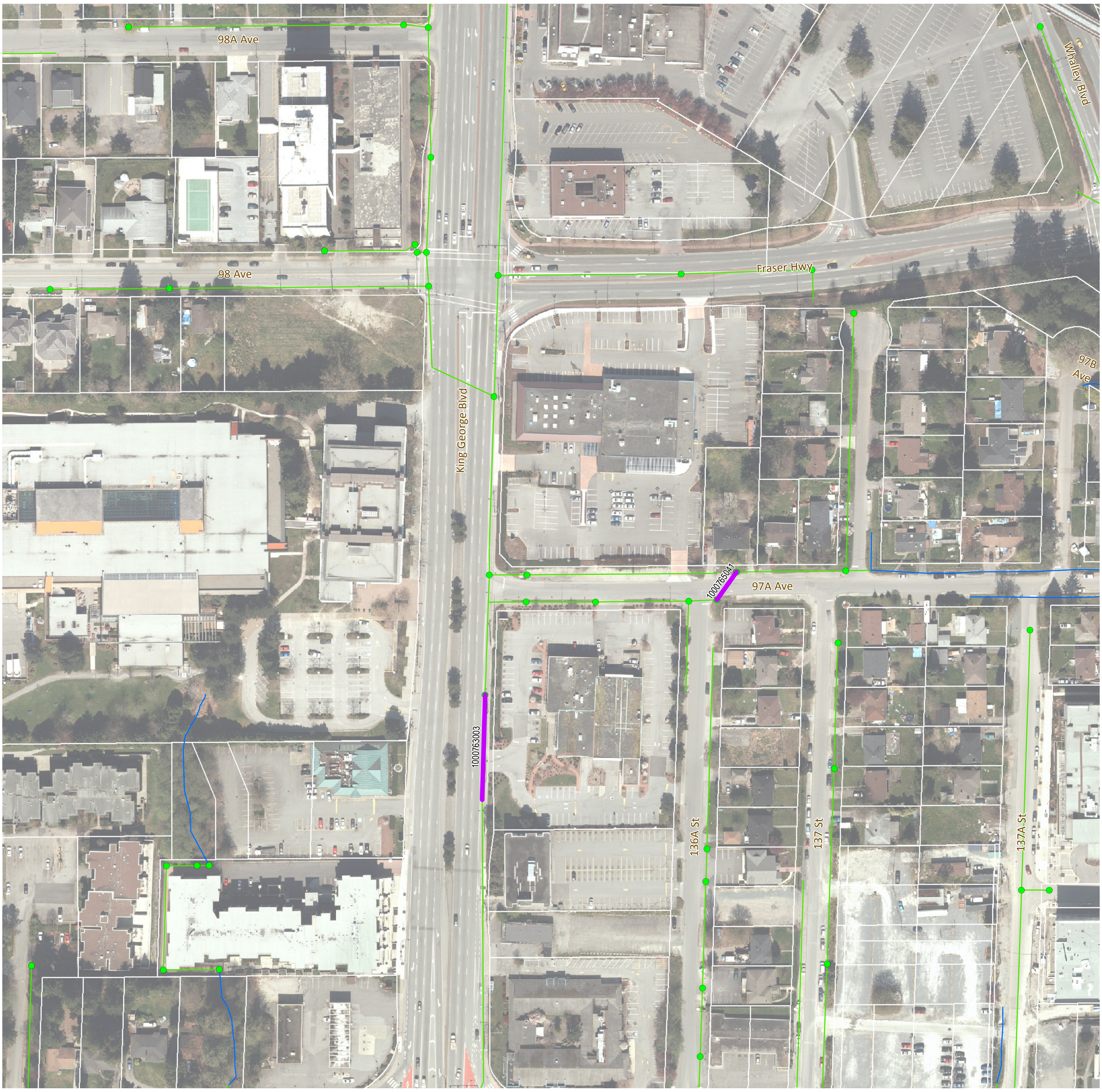
Capital Plan - Priority of Drainage System Improvements
Key Plan Area 5

Figure H-6



Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000763003	43,379	0.36	0.53	750	900	48	900	6
1000765041	5,013	0.05	0.06	250	300	16	320	6

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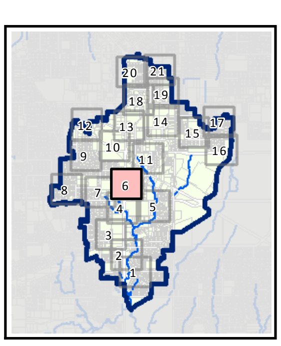

Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 6

Figure H-7

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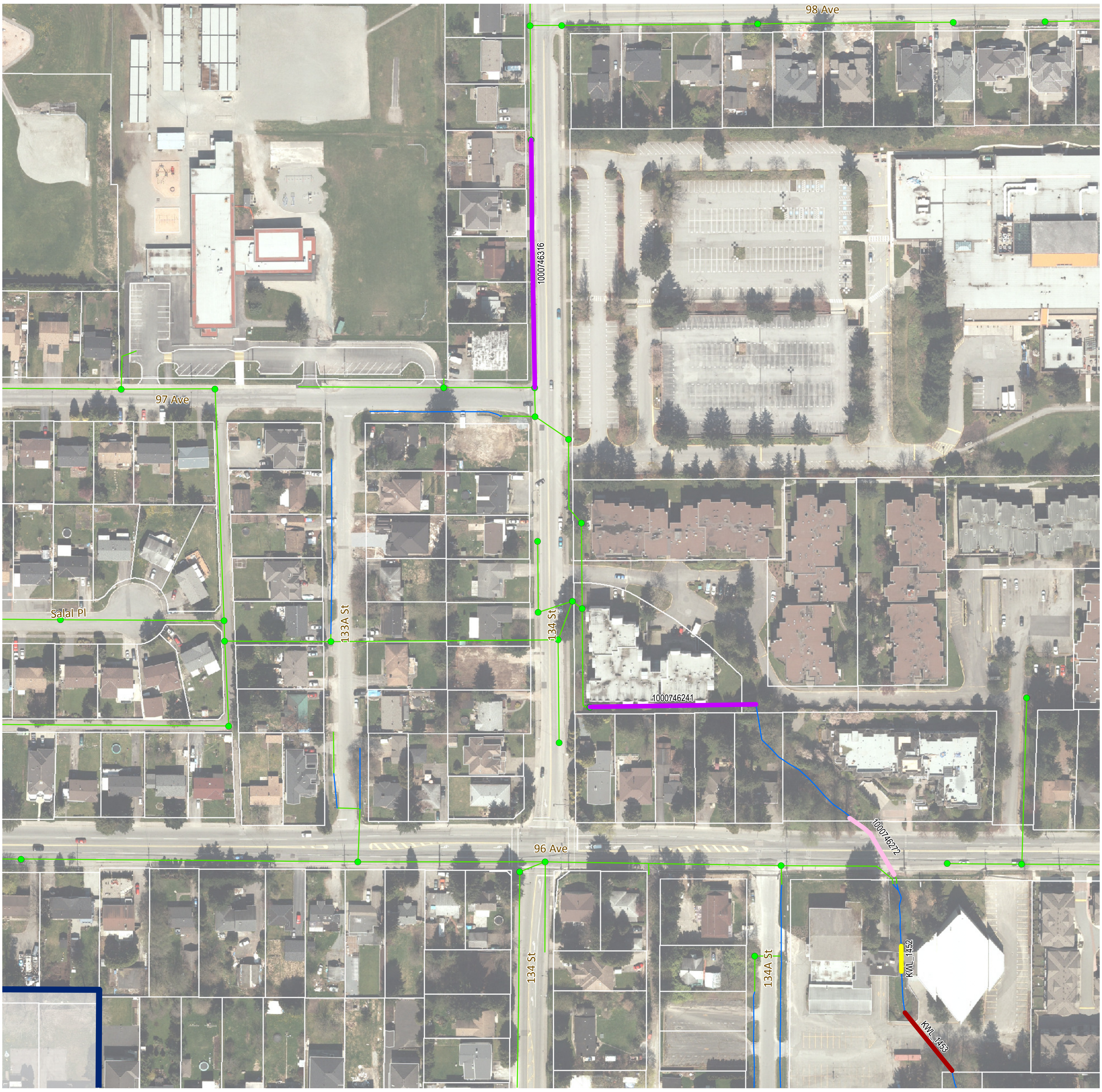
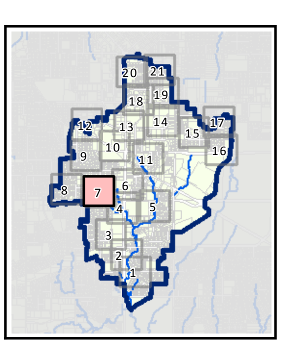


Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000746241	68,579	1.11	1.75	750	900	76	900	6
1000746272	60,636	2.07	2.95	1050	1350	34	1800	4
1000746316	147,997	0.46	0.86	900	1050	114	1300	6
KWL_1452	15,263	1.30	2.52	750	1050	12	1300	5
KWL_1453	51,543	1.92	4.17	750	1200	34	1500	1

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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City of Surrey
Quibble Creek Integrated Stormwater Management Plan

Capital Plan - Priority of Drainage System Improvements
Key Plan Area 7

Figure H-8

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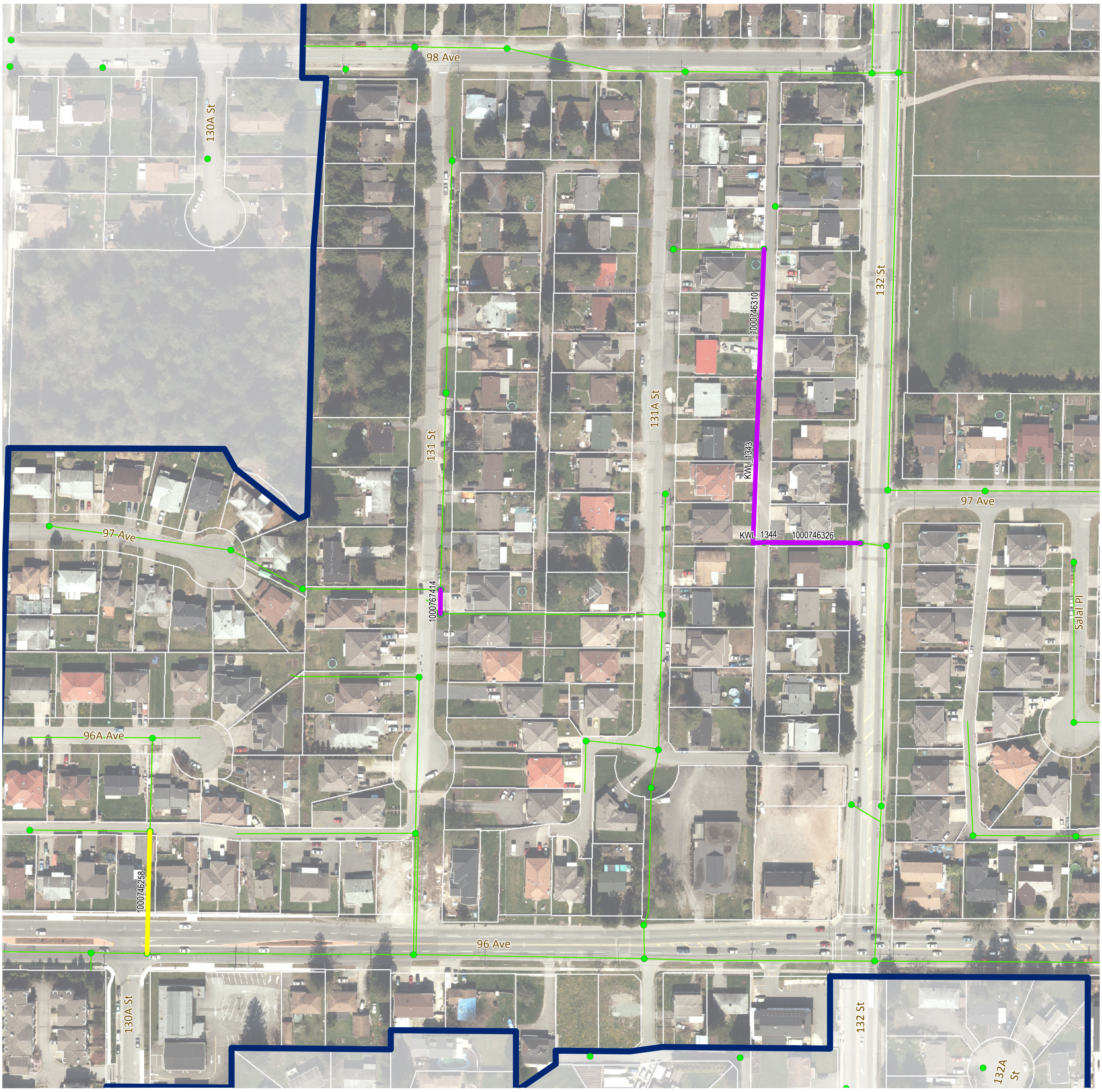
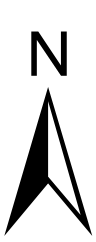
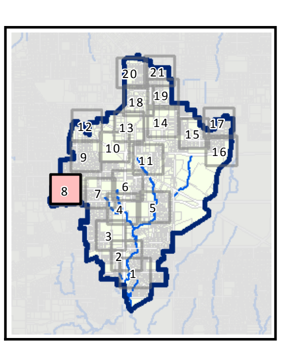


Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000746258	28,048	0.04	0.05	300	525	56	500	5
1000746310	16,667	0.02	0.03	200	250	60	280	6
1000746326	12,376	0.04	0.06	200	250	44	280	6
1000767414	4,264	0.09	0.12	300	375	11	380	6
KWL_1343	21,165	0.03	0.04	200	250	76	280	6
KWL_1344	1,455	0.04	0.05	200	250	5	280	6





Legend

Study Area

Conduits

Watercourse

Major System Upgrades

(Priority 1) Fail Existing - 100 Year - Flooding on Surface

(Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

(Priority 2) Fail Existing - 5 Year - Flooding on Surface

(Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m

(Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required

(Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

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Quibble Creek Integrated Stormwater Management Plan

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Date February, 2014

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 8

Figure H-9

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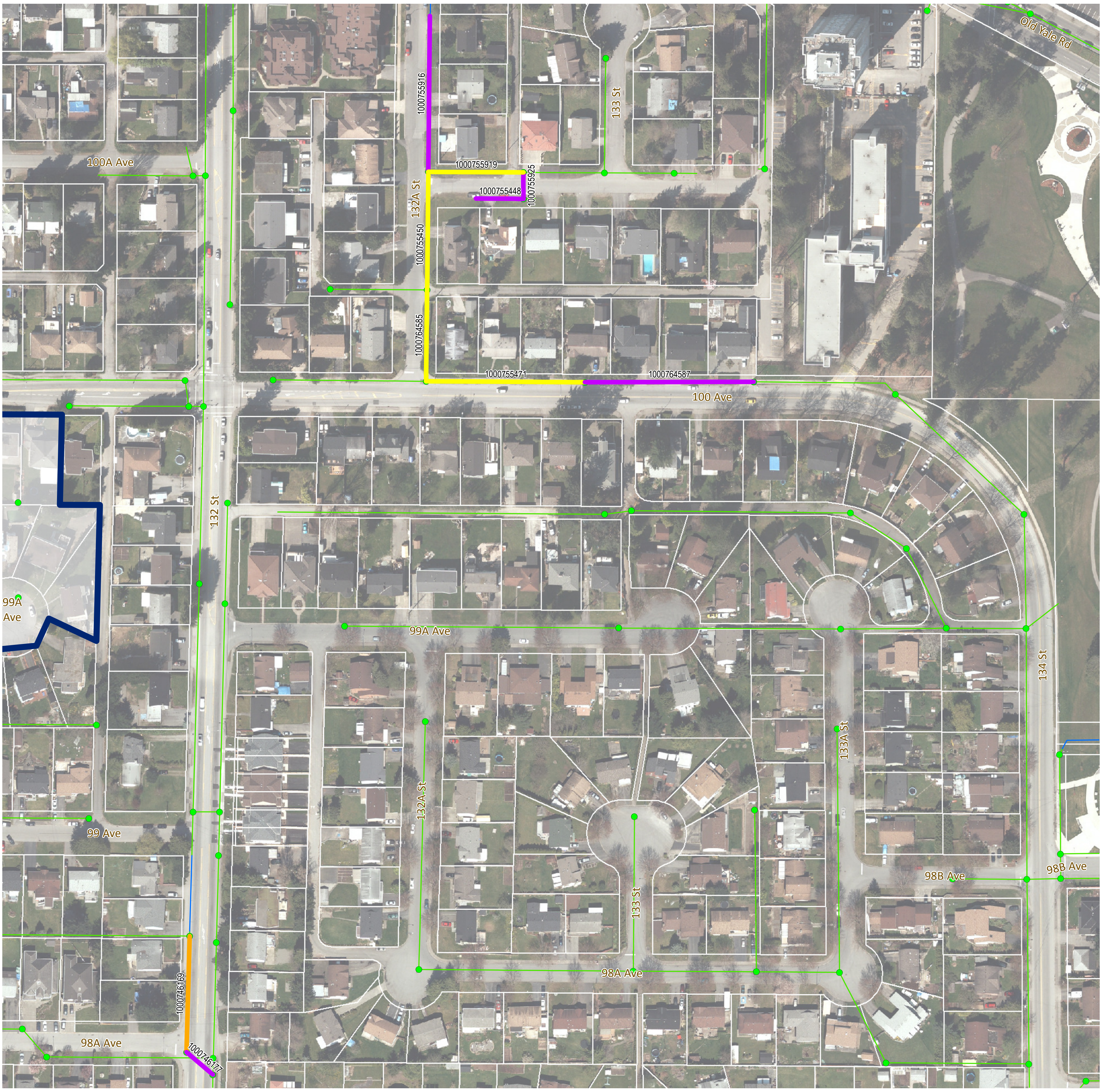
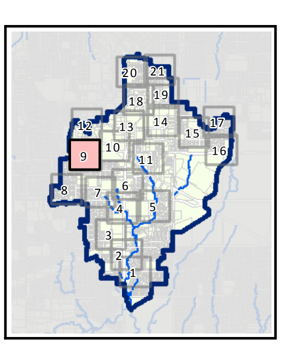
Author: DLee



Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000746169	22,944	0.23	0.34	300	450	53	430	3
1000746177	6,023	0.24	0.35	300	375	16	380	6
1000755448	6,960	0.00	0.07	250	300	22	320	6
1000755450	23,320	0.04	0.11	250	450	54	430	5
1000755471	27,676	0.06	0.16	250	375	73	380	5

Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000755916	22,900	0.01	0.05	250	300	72	320	6
1000755919	21,790	0.02	0.08	250	525	44	500	5
1000755925	3,891	0.01	0.01	250	300	12	320	6
1000764585	18,074	0.05	0.14	250	450	42	430	5
1000764587	29,420	0.07	0.17	300	375	77	380	6

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Quibble Creek Integrated Stormwater Management Plan

Project No.	Date
471-239	February, 2014

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 9

Figure H-10

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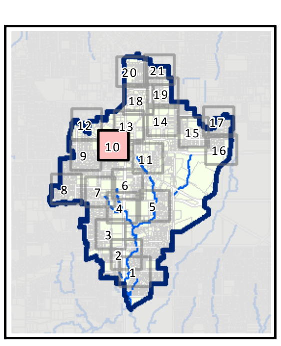
Author: DLee

Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000755449	49,656	0.23	0.47	600	675	76	650	6
1000755453	49,789	0.24	0.48	600	675	77	650	6

N



Legend

Study Area

Conduits

Watercourse

Major System Upgrades

(Priority 1) Fail Existing - 100 Year - Flooding on Surface

(Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

(Priority 2) Fail Existing - 5 Year - Flooding on Surface

(Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m

(Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required

(Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

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Quibble Creek Integrated Stormwater Management Plan

Project No. 471-239

Date February, 2014

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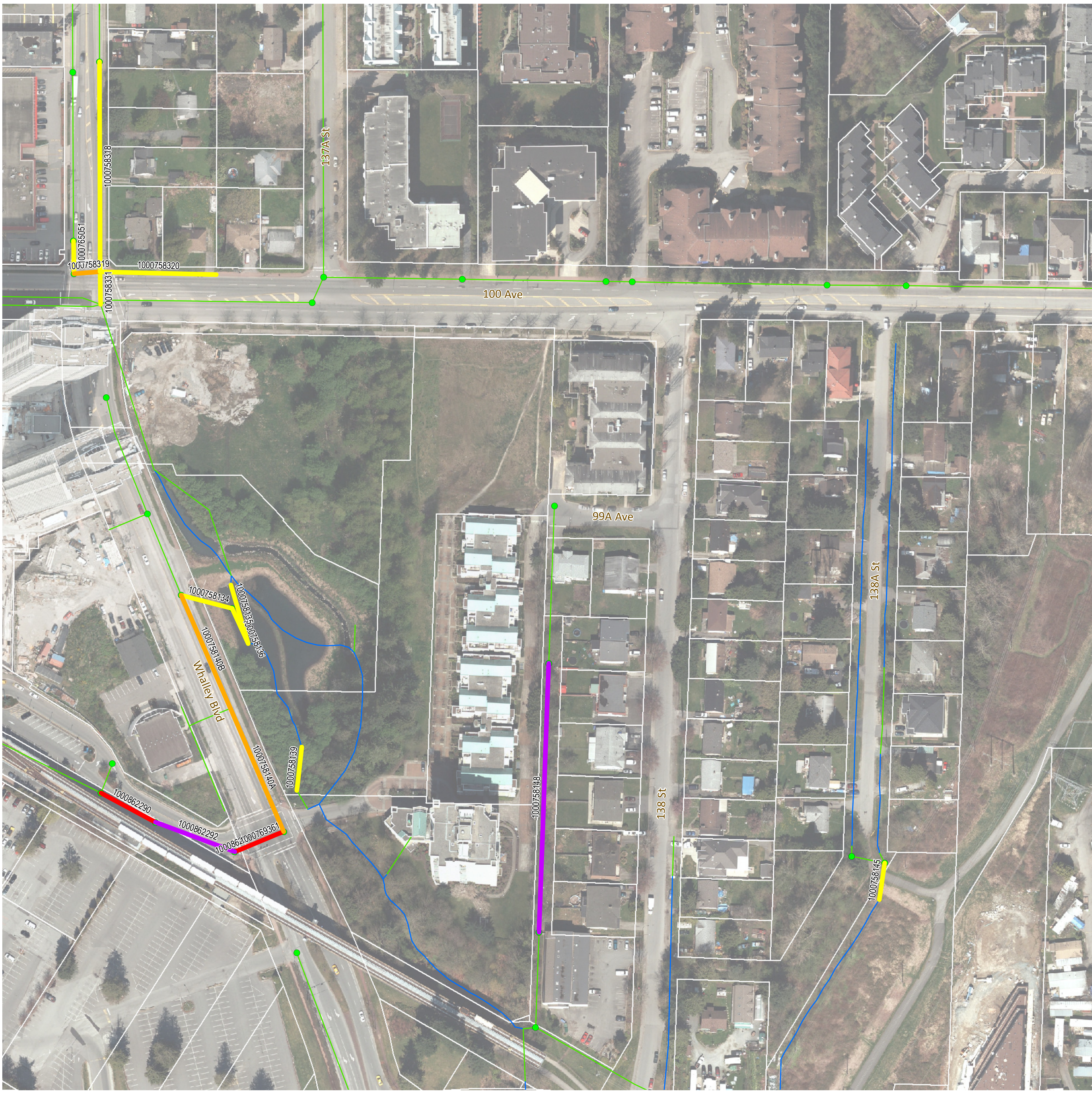
Capital Plan - Priority of Drainage System Improvements
Key Plan Area 10

Figure H-11

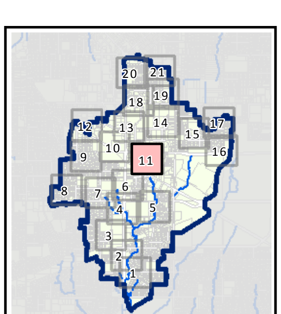
Path: O:\0400-0499\471-239\430-GIS\MXD-Rp\471239_FigH-2_22.mxd Date Saved: 17/02/2014 11:11:25 AM
Author: DLee



Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000758134	14,423	0.09	0.47	450	600	24	600	5
1000758135	18,198	0.24	0.70	525	675	28	650	5
1000758136	11,504	0.10	0.81	450	675	18	650	5
1000758139	25,989	0.21	0.74	750	1050	20	1300	5
1000758145	7,266	0.07	0.15	300	450	17	430	5
1000758148	46,903	0.09	0.12	300	375	123	380	6
1000758318	57,786	0.13	0.32	450	600	96	600	5
1000758319	10,828	0.20	1.10	375	900	12	900	3
1000758320	34,554	0.05	0.38	375	675	53	650	5

Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000758331	13,532	0.30	2.07	600	900	15	900	5
1000765051	13,474	0.19	1.21	600	900	15	900	5
1000769361	6,791	0.06	0.12	200	300	21	320	2
1000862290	10,754	0.07	0.09	200	375	28	380	2
1000862292	10,844	0.06	0.10	200	250	39	280	6
1000862293	1,142	0.06	0.12	200	375	3	380	2
1000758140A	19,666	0.06	0.12	200	300	61	320	3
1000758140B	21,519	0.07	0.16	200	375	57	380	3

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Quibble Creek Integrated Stormwater Management Plan

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 11

Figure H-12

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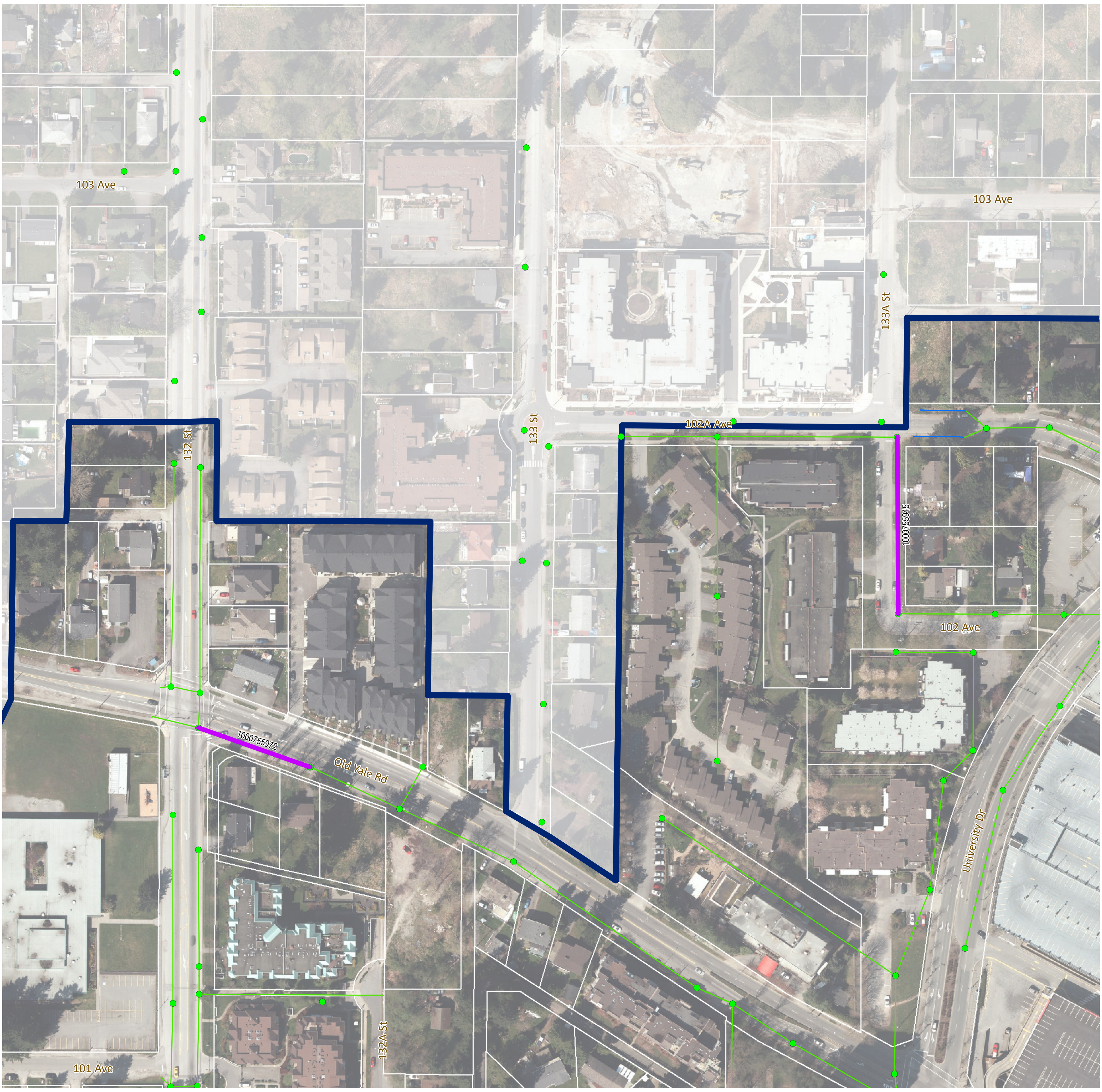
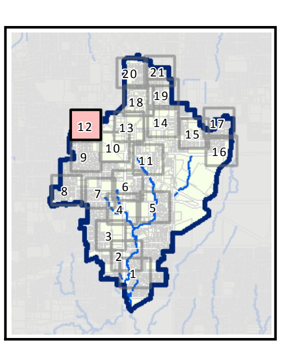


Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000755945	30,815	0.04	0.06	300	375	81	380	6
1000755972	20,634	0.04	0.06	300	375	54	380	6

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

Study Area

Conduits

Watercourse

Major System Upgrades

(Priority 1) Fail Existing - 100 Year - Flooding on Surface

(Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

(Priority 2) Fail Existing - 5 Year - Flooding on Surface

(Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m

(Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required

(Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Quibble Creek Integrated Stormwater Management Plan

Capital Plan - Priority of Drainage System Improvements
Key Plan Area 12

Figure H-13

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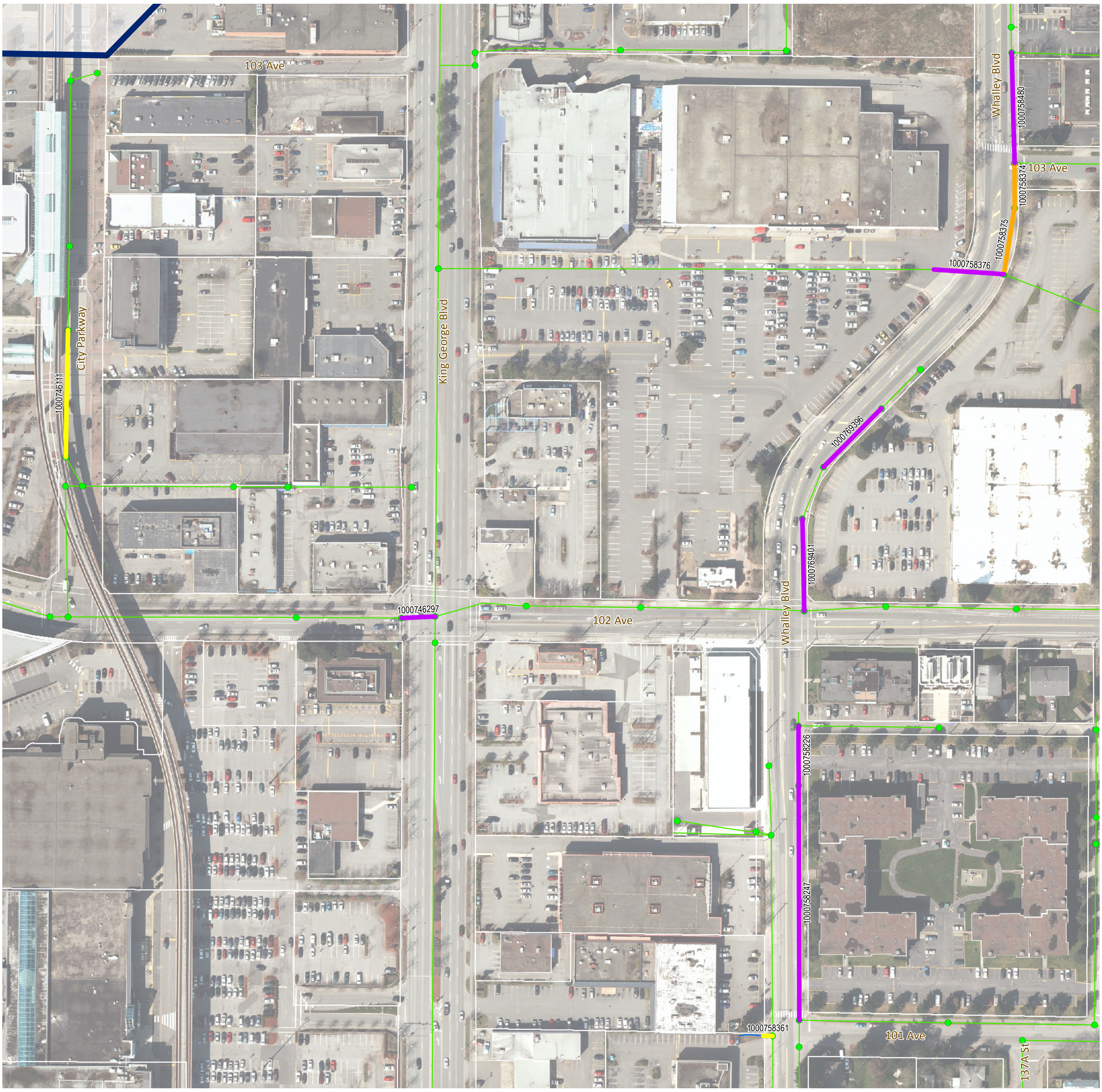
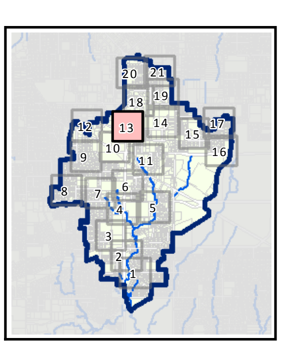


Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000746111	40,688	0.10	0.13	450	750	58	700	5
1000746297	13,927	0.35	0.50	750	900	15	900	6
1000758226	10,424	0.05	0.07	300	375	27	380	6
1000758247	40,964	0.05	0.07	300	375	108	380	6
1000758361	1,395	0.03	0.04	200	300	4	320	5
1000758374	14,399	0.85	1.44	600	750	21	700	3

Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000758375	27,785	0.85	1.45	600	900	31	900	3
1000758376	41,889	1.24	2.06	900	1050	32	1300	6
1000758480	33,019	0.70	1.26	600	675	51	650	6
1000769396	10,624	0.05	0.07	200	250	38	280	6
1000769401	13,558	0.06	0.08	250	300	42	320	6

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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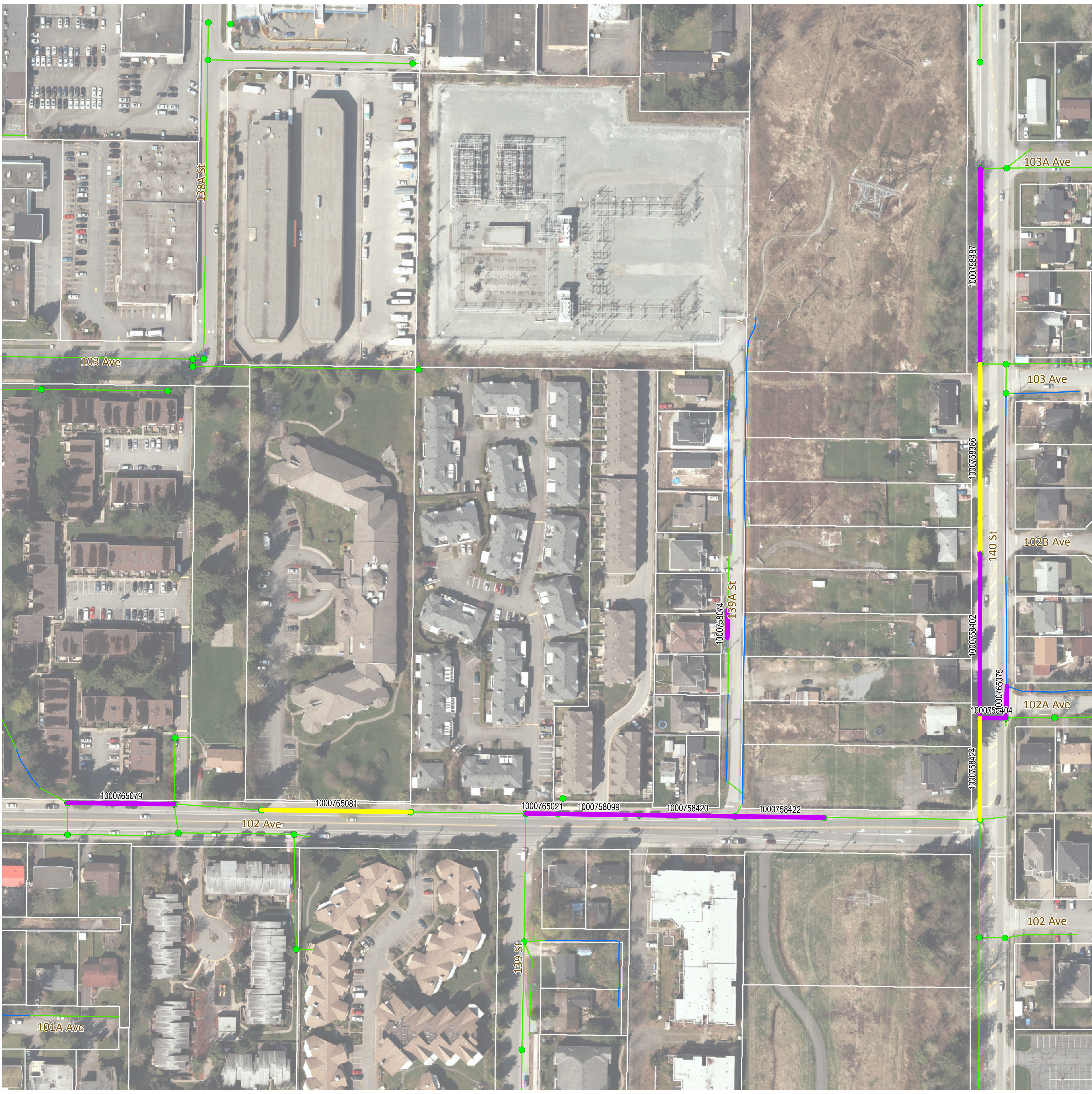
Capital Plan - Priority of Drainage System Improvements Key Plan Area 13

Figure H-14

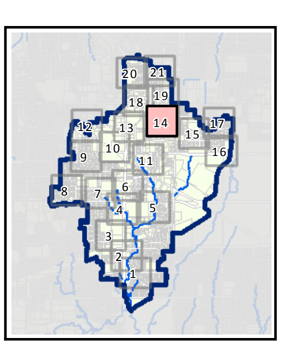
Path: O:\0400-0499\471-239\430-GIS\MXD-Rp\471239_FigH-2_22.mxd Date Saved: 17/02/2014 11:11:25 AM
Author: DLee



Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000758074	4,064	0.02	0.05	250	300	13	320	6
1000758099	24,154	0.48	0.62	600	675	37	650	6
1000758386	37,354	0.14	0.22	300	450	87	430	5
1000758402	32,430	0.14	0.23	375	450	75	430	6
1000758404	3,805	0.10	0.13	250	300	12	320	6
1000758420	28,609	0.47	0.62	600	675	44	650	6
1000758422	20,247	0.37	0.49	450	525	40	500	6

Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000758424	27,948	0.24	0.35	450	600	47	600	5
1000758487	34,105	0.08	0.10	300	375	90	380	6
1000765021	9,497	0.48	0.63	600	675	15	650	6
1000765075	5,546	0.06	0.10	300	375	15	380	6
1000765079	24,386	0.55	0.86	450	525	49	500	6
1000765081	47,940	0.53	0.71	600	750	68	700	5

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Quibble Creek Integrated Stormwater Management Plan

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 14

Figure H-15

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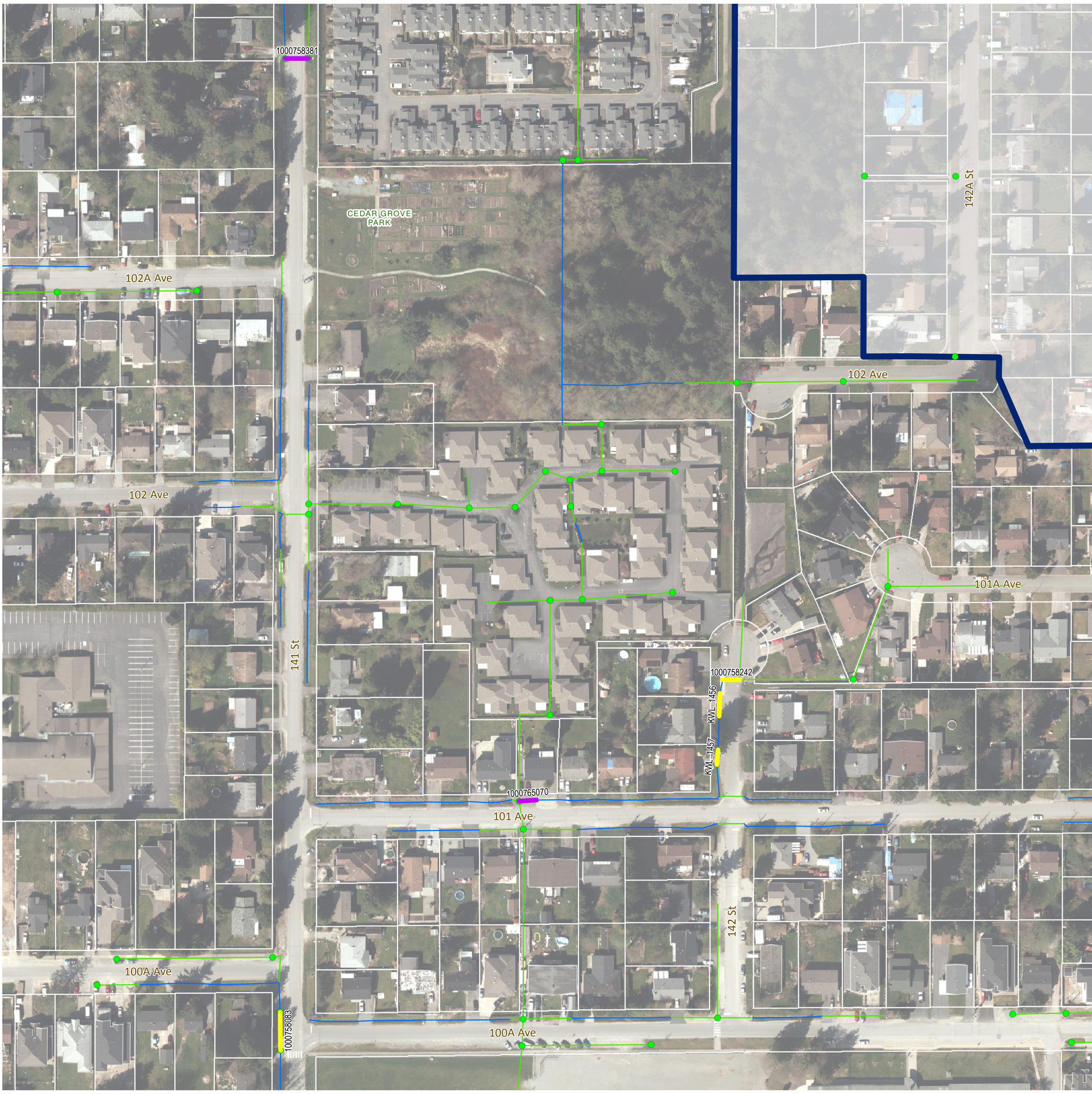
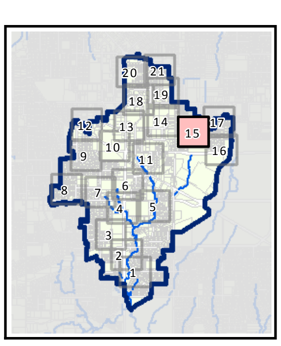


Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000758083	6,631	0.03	0.10	250	375	17	380	5
1000758242	2,964	0.05	0.07	250	375	8	380	5
1000758381	3,072	0.02	0.02	200	250	11	280	6
1000765070	2,539	0.07	0.09	250	300	8	320	6
KWL_1456	3,986	0.05	0.09	250	375	10	380	5
KWL_1457	2,605	0.05	0.07	250	375	7	380	5

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 15

Figure H-16

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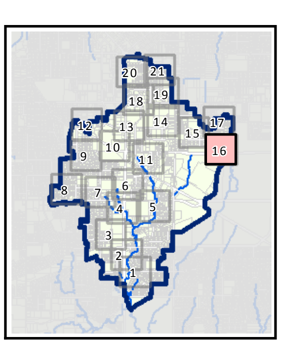
Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000757945	6,900	0.14	0.18	525	600	11	600	6
1000758151	32,888	0.61	0.76	900	1050	25	1300	6
1000758323	22,851	0.19	0.25	450	525	46	500	6
1000758351	22,379	0.13	0.17	375	450	52	430	6
1000765058	27,301	0.59	1.08	900	1050	21	1300	4

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

Study Area

Conduits

Watercourse

Major System Upgrades

(Priority 1) Fail Existing - 100 Year - Flooding on Surface

(Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

(Priority 2) Fail Existing - 5 Year - Flooding on Surface

(Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m

(Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required

(Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Date February, 2014

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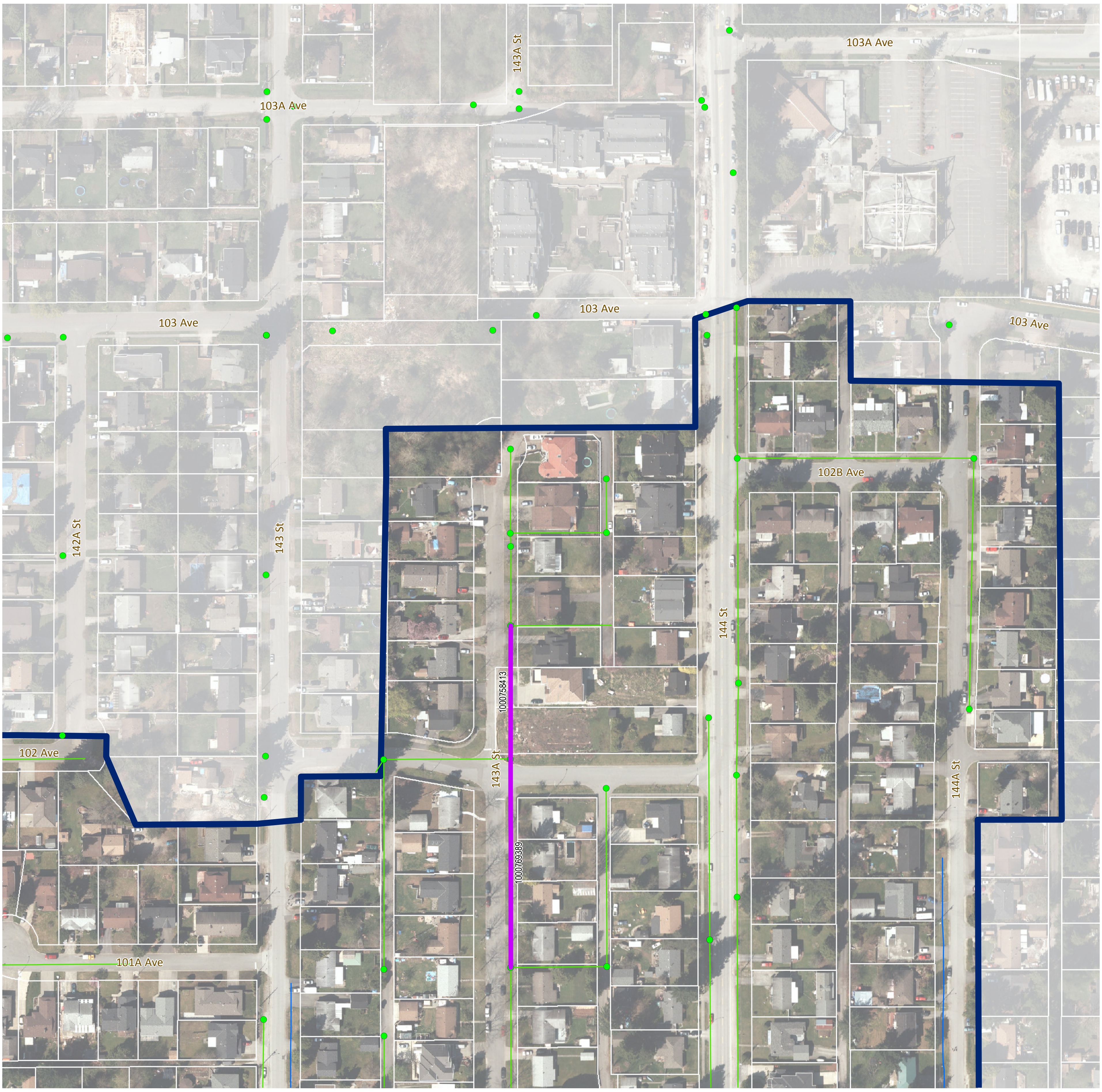
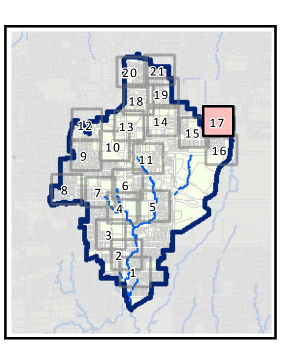
Capital Plan - Priority of Drainage System Improvements
Key Plan Area 16

Figure H-17



Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000758413	19,565	0.04	0.06	250	300	61	320	6
1000769389	36,419	0.07	0.09	300	375	96	380	6

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Quibble Creek Integrated Stormwater Management Plan

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 17

Figure H-18

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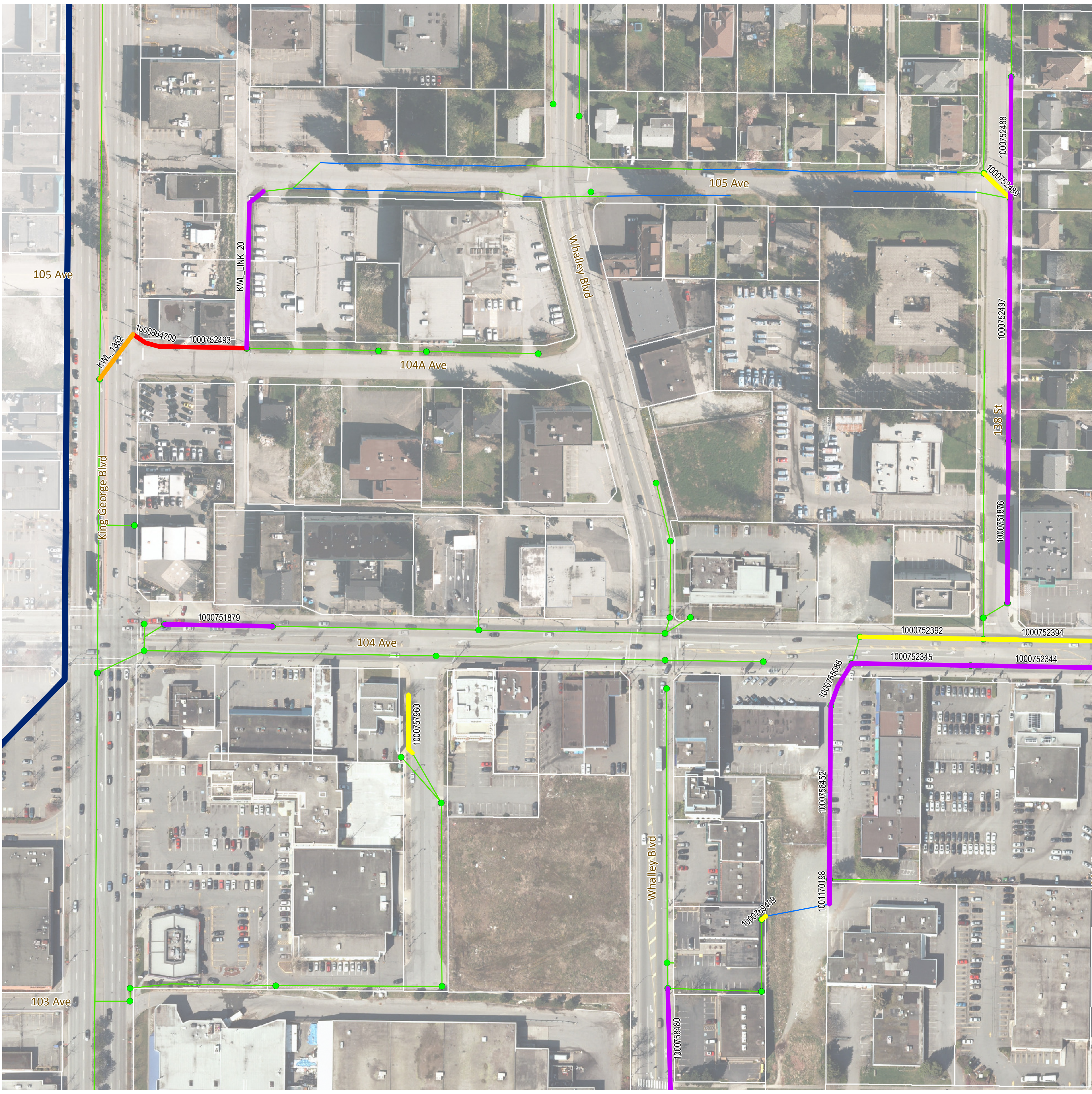
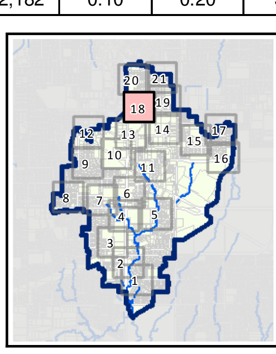


Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000751876	37,252	0.12	0.23	450	525	75	500	6
1000751879	15,859	0.08	0.10	250	300	50	320	6
1000752344	44,679	0.09	0.18	375	450	104	430	6
1000752345	23,405	0.10	0.08	375	450	54	430	6
1000752392	36,711	0.47	1.04	450	675	56	650	5
1000752394	68,707	0.28	0.73	450	750	98	700	5
1000752488	21,277	0.07	0.14	300	375	56	380	6
1000752489	5,375	0.02	0.04	200	300	17	320	5
1000752493	12,972	0.13	0.19	250	375	34	380	2
1000752497	42,182	0.10	0.20	300	375	111	380	6

Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000757960	6,567	0.00	0.00	75	200	27	240	5
1000758452	51,775	0.58	1.13	600	675	80	650	6
1000758480	33,019	0.70	1.26	600	675	51	650	6
1000765086	14,200	0.58	1.13	600	675	22	650	6
1000769409	1,709	0.68	1.19	450	750	2	700	5
1000864709	7,352	0.13	0.20	250	375	19	380	2
1001170198	7,365	0.62	1.17	600	675	11	650	6
KWL_1352	9,689	0.13	0.22	250	375	25	380	3
KWL_LINK_20	23,983	0.08	0.10	250	300	75	320	6

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

- (Priority 2) Fail Existing - 5 Year - Flooding on Surface
- (Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m
- (Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required
- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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consulting engineers

Project No. 471-239

Date February, 2014

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City of Surrey
Quibble Creek Integrated Stormwater Management Plan

Capital Plan - Priority of Drainage System Improvements
Key Plan Area 18

Figure H-19

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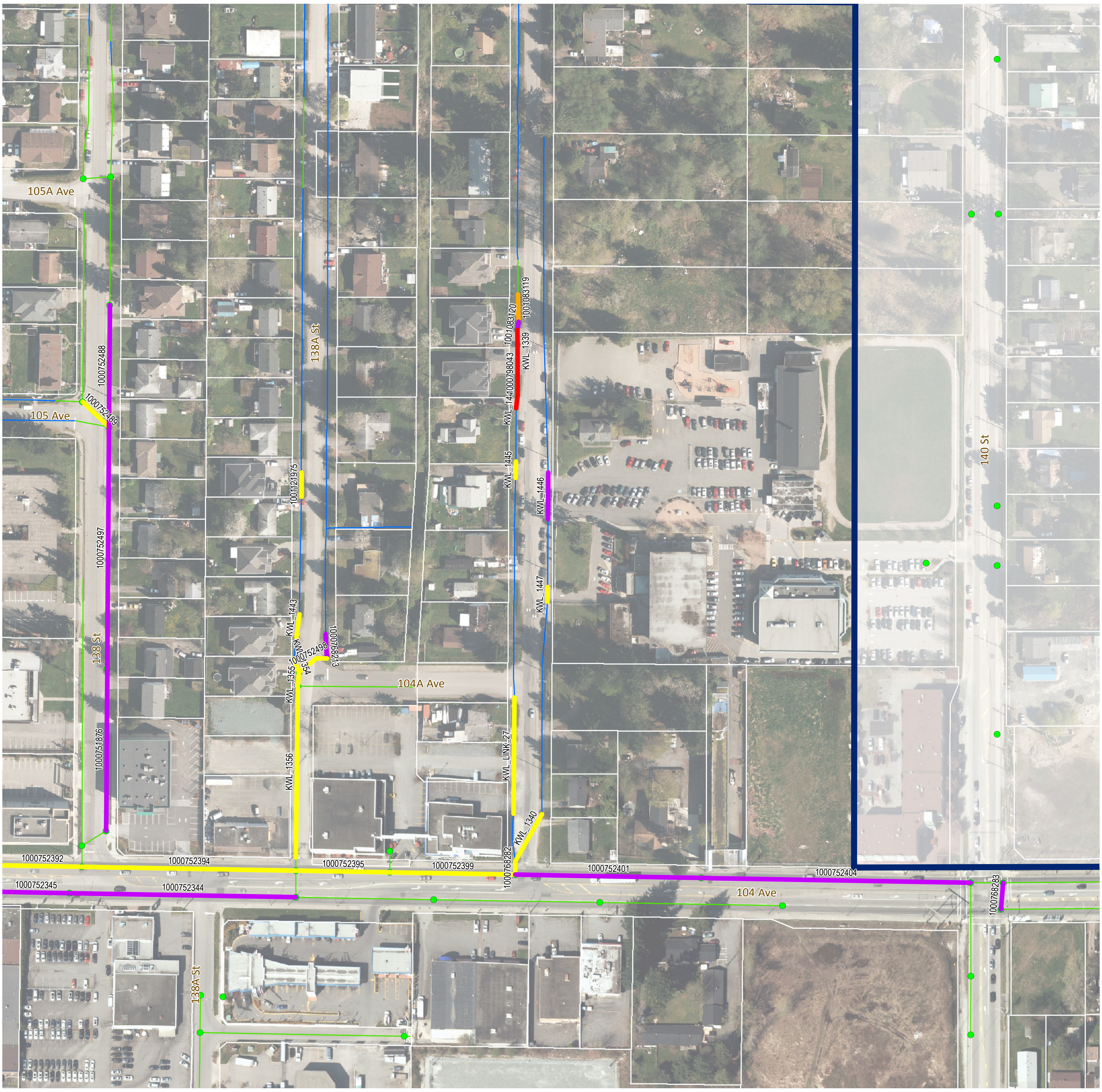
Author: DLee

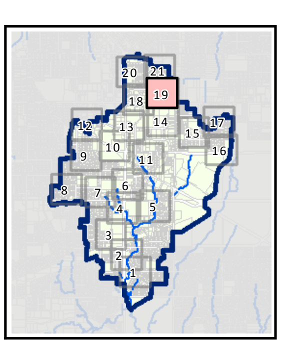


Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000751876	37,252	0.12	0.23	450	525	75	500	6
1000752344	44,679	0.09	0.18	375	450	104	430	6
1000752345	23,405	0.10	0.08	375	450	54	430	6
1000752392	36,711	0.47	1.04	450	675	56	650	5
1000752394	68,707	0.28	0.73	450	750	98	700	5
1000752395	18,519	0.19	0.46	300	450	43	430	5
1000752399	24,746	0.19	0.45	300	450	58	430	5
1000752401	27,309	0.08	0.11	250	300	85	320	6
1000752404	39,565	0.05	0.08	250	300	124	320	6
1000752488	21,277	0.07	0.14	300	375	56	380	6
1000752489	5,375	0.02	0.04	200	300	17	320	5
1000752497	42,182	0.10	0.20	300	375	111	380	6
1000752498	5,721	0.03	0.14	250	375	15	380	5

Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000768213	3,537	0.03	0.10	250	300	11	320	6
1000768282	2,318	0.11	0.33	250	375	6	380	5
1000768283	3,916	0.03	0.06	250	300	12	320	6
1000798043	7,486	0.06	0.12	250	375	20	380	2
1001083119	6,341	0.07	0.11	300	525	13	500	3
1001083120	1,444	0.09	0.21	300	375	4	380	6
1001121975	4,237	0.06	0.12	250	375	11	380	5
KWL_1339	3,322	0.06	0.12	250	300	10	320	2
KWL_1340	9,449	0.07	0.17	250	375	25	380	5
KWL_1354	2,843	0.06	0.16	250	450	7	430	5
KWL_1355	3,261	0.08	0.29	300	525	7	500	5
KWL_1356	39,289	0.08	0.24	300	525	79	500	5
KWL_1443	4,068	0.05	0.14	250	375	11	380	5

Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
KWL_1444	2,227	0.06	0.12	250	375	6	380	2
KWL_1445	3,771	0.06	0.13	250	525	8	500	5
KWL_1446	6,815	0.02	0.09	250	300	21	320	6
KWL_1447	2,563	0.07	0.15	250	375	7	380	5
KWL_LINK_27	20,281	0.04	0.15	200	375	53	380	5

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

Study Area

Conduits

Watercourse

Major System Upgrades

(Priority 1) Fail Existing - 100 Year - Flooding on Surface

(Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

(Priority 2) Fail Existing - 5 Year - Flooding on Surface

(Priority 3) Fail Existing - 5 Year - Surcharge >15 min and .3m

(Priority 5) Fail Future - 5 Year - Capacity - ≥ 2 Pipe Diameter Upgrade Required

(Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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Quibble Creek Integrated Stormwater Management Plan

Project No. 471-239

Date February, 2014

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 19

Figure H-20

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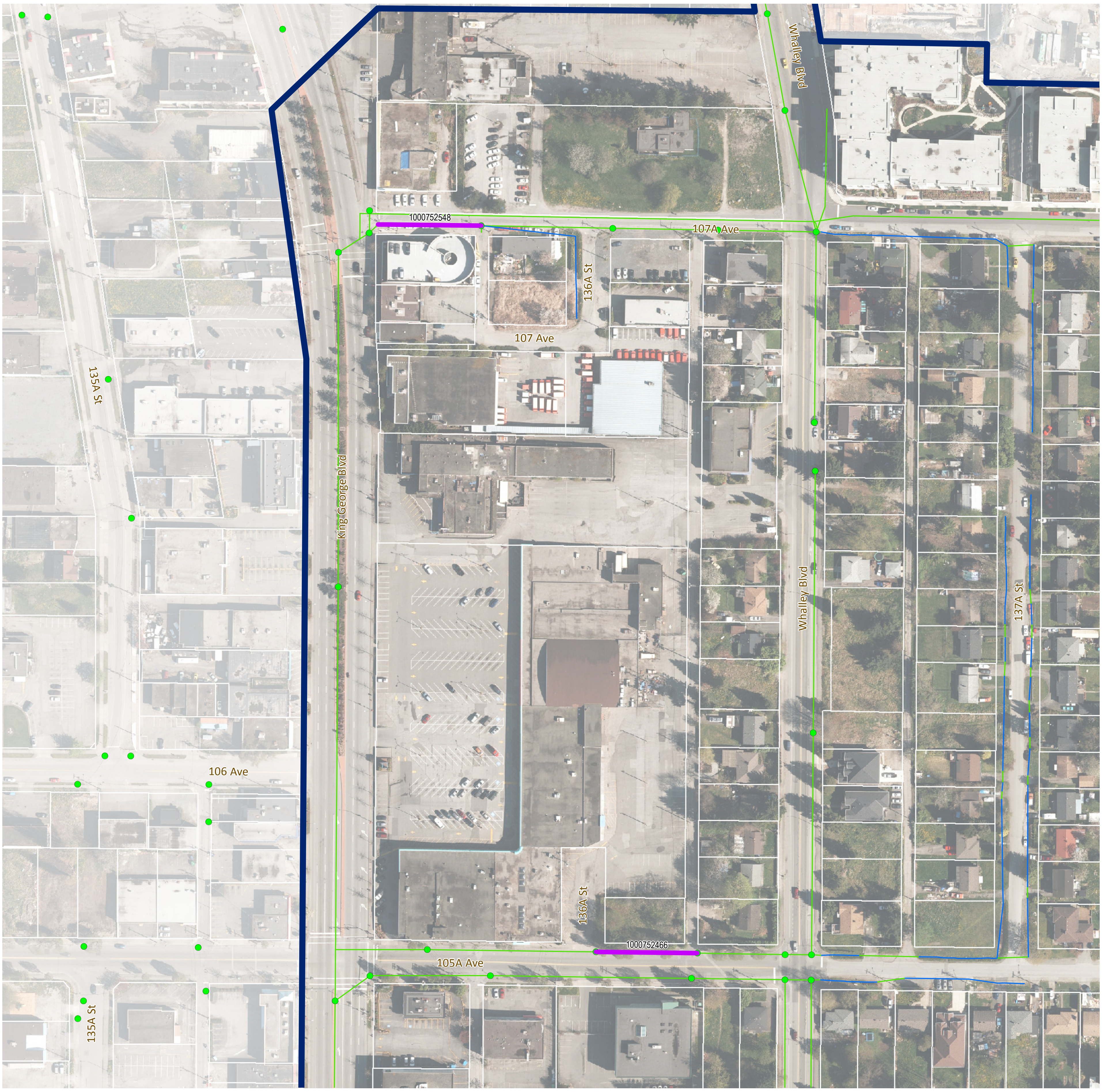
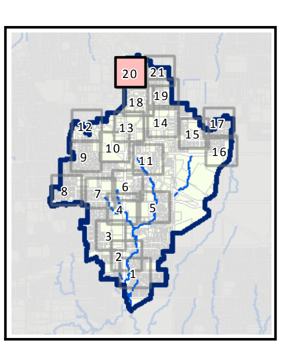


Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000752466	17,671	0.12	0.22	300	375	47	380	6
1000752548	17,971	0.14	0.21	300	375	47	380	6

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

- (Priority 1) Fail Existing - 100 Year - Flooding on Surface
- (Priority 4) Fail Future - 100 Year - Capacity

Minor System Upgrades

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Quibble Creek Integrated Stormwater Management Plan

Project No. 471-239

Date February, 2014

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 20

Figure H-21

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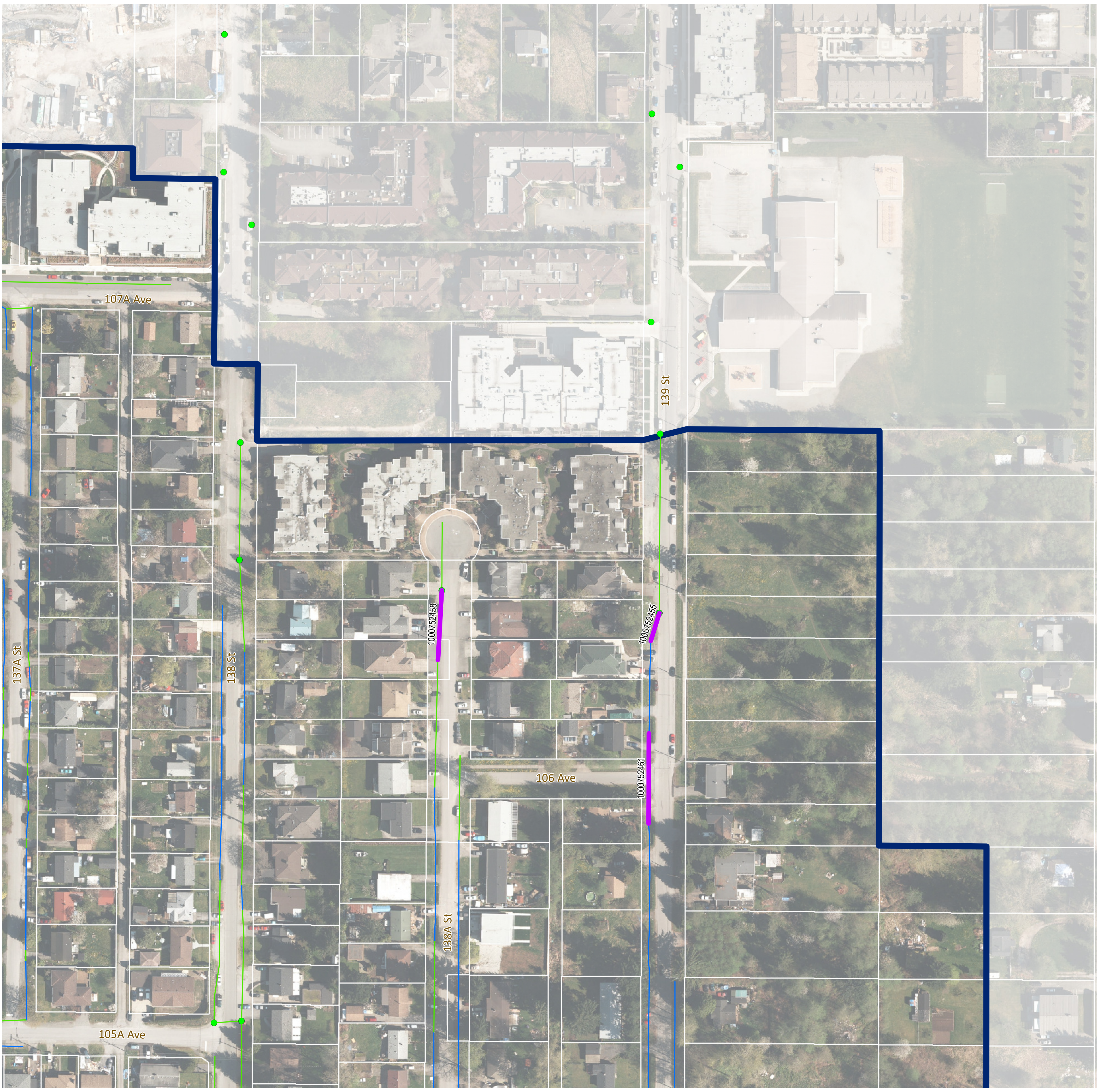
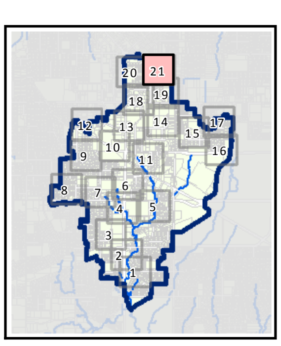


Conduit ID	Est. Cost ($)	Existing 100-Year Flow (m3/s)	Future 100-Year Flow (m3/s)	Existing Size (mm)	Upgrade Size (mm)	Length (m)	Unit Cost ($/m)	Priority
1000752455	4,306	0.03	0.03	250	300	13	320	6
1000752458	8,966	0.02	0.03	200	250	32	280	6
1000752461	13,252	0.04	0.05	250	300	41	320	6

N



Reference: Reference: GIS data from City of Surrey Open Data Catalogue.

Legend

- Study Area
- Conduits
- Watercourse

Major System Upgrades

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Minor System Upgrades

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- (Priority 6) Fail Future - 5 Year - Capacity - 1 Pipe Diameter Upgrade Required

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City of Surrey
Quibble Creek Integrated Stormwater Management Plan

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Capital Plan - Priority of Drainage System Improvements
Key Plan Area 21

Figure H-22

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Appendix I

Design and Maintenance Checklists

Absorbent Landscaping Assessment Checklist

CITY OF SURREY

File No.: ____________________________

Project: ____ **Reviewer:** ______________________________

Site: ____ **Date/Time:** ______________________________

Swale Location					
Hydraulics	Minor design flow (m^3/s):		Major design flow (m^3/s):		
Area	Catchment area (ha):		Absorbent Landscape area (ha):		
Design sizing				**Y**	**N**
I/P Ratio determined based on curves to achieve treatment and volume reduction?					
Absorbent growing media depth between 150 – 450 mm?					
Inlet Zone/Hydraulics				**Y**	**N**
Overall flow conveyance system, including overflow, sufficient for minor system design flow?					
Slope of absorbent lanscaping >1% and 2%?					
Mannings ‘*n*’ used appropriate for proposed vegetation and flow depth?					
Designed high flow route over or bypassing absorbent landscaping for major design flow?					
Inlet flows appropriately distributed?					
Energy dissipation provided at inlets/ concentrated flows?					
Velocities will not cause scour?					
Drop/set down of 50 to 100 mm below kerb invert incorporated?					
Safety and Maintenance				**Y**	**N**
Maintenance access provided as required (mowing or other)?					
Vegetation				**Y**	**N**
Plant species selected can tolerate periodic inundation and drought and design velocities?					
Plant species selected integrate with surrounding landscape design?					
Standard soil specification or custom soil by Professional Agrologist?					

Bioretention Area Design Assessment Checklist

CITY OF SURREY

File No.: ____________________

Project: ____ **Reviewer:** ____________________

Site: ____ **Date/Time:** ____________________

Bioretention Area Location					
Hydraulics	Minor design flow (m^3/s):		Major design flow (m^3/s):		
Area	Catchment area (ha):		Bioretention area (ha):		
Design Sizing				**Y**	**N**
Base area sized for Maximum I/P ratio (longevity) and water quality treatment?					
Base area sized for Volume Reduction?					
Footprint includes required base area and at least minimum side slopes?					
Inlet Zone/Hydraulics				**Y**	**N**
Overall flow conveyance system, including overflow, sufficient for minor system design flow?					
Designed high flow route through or bypassing bioretention for major design flow?					
Maximum upstream flood conveyance width does not impact on traffic amenity?					
Velocities at inlets and within bioretention system will not cause scour?					
Drop/setdown of 50-100 mm provided for flat inlet/entry areas?					
Erosion protection for all point/concentrated flows?					
Collection System				**Y**	**N**
Perforated underdrain capacity > infiltration capacity of filter media?					
Direct connection to storm sewer at least minimum slope and within required length?					
Granular filter layer or geotextile barrier provided to prevent clogging of rock drainage layer?					
Underdrain at top of drain rock for infiltration or bottom of rock for non-infiltration facility?					
Trench dams included for utility crossings?					
Basin				**Y**	**N**
Maximum ponding depth and velocity will not create safety hazards?					
Base of bioretention flat or sloped less than 1%?					
Base area accessible for appropriate maintenance (4:1 side slopes if mowing)?					
Groundwater > 0.6 m below rock drainage layer?					
Vegetation				**Y**	**N**
Plant species selected can tolerate periodic inundation and drought?					
Plant species selected integrate with surrounding landscape design?					
Standard soil specification or custom soil by Professional Agrologist?					

Bioswale Design Assessment Checklist

CITY OF SURREY

File No.: ____________________________

Project: ____ **Reviewer:** ______________________________

Site: ____ **Date/Time:** ______________________________

Swale Location					
Hydraulics	Minor design flow (m^3/s):		Major design flow (m^3/s):		
Area	Catchment area (ha):		Bioretention area (m^2):		
Design Sizing				**Y**	**N**
Base area sized for Maximum I/P ratio (longevity) and water quality treatment?					
Base area sized for Volume Reduction?					
Footprint includes required base area and at least minimum side slopes?					
Inlet Zone/Hydraulics				**Y**	**N**
Overall flow conveyance system, including overflow, sufficient for minor system design flow?					
Longitudinal slope of swale invert >1% and 24%?					
Mannings '*n*' used appropriate for proposed vegetation and flow depth?					
Designed high flow route through or bypassing bioswale for major design flow?					
Maximum upstream flood conveyance width does not impact on traffic amenity?					
Inlet flows appropriately distributed?					
Energy dissipation provided at inlets/ concentrated flows?					
Velocities within bioretention cells will not cause scour?					
Drop/set down of 50 to 100 mm below curb invert incorporated?					
Collection System				**Y**	**N**
Perforated underdrain capacity > infiltration capacity of filter media?					
Direct connection to storm sewer at least minimum slope and within required length?					
Granular filter layer or geotextile barrier provided to prevent clogging of rock drainage layer?					
Underdrain at top of drain rock for infiltration or bottom of rock for non-infiltration facility?					
Trench dams included for utility crossings?					
Safety and Maintenance				**Y**	**N**
Maximum ponding depth and velocity will not create safety hazards?					
Groundwater > 0.6 m below rock drainage layer?					
Maintenance access provided to invert of conveyance channel?					
Vegetation				**Y**	**N**
Plant species selected can tolerate periodic inundation and drought and design velocities?					
Plant species selected integrate with surrounding landscape design?					
Standard soil specification or custom soil by Professional Agrologist?					

Design Review Checklist

CITY OF SURREY

File No.: ______________________

Project: ______________________ **Inspector:** ______________________

Site: ______________________ **Date/Time:** ______________________

This is a: ☐ Field Visit ☐ Design Review

1. Native Soil Infiltration Rates

    Water does infiltrate into rock, clay, and glacial till…just slowly.
    Source Controls are focusing on the small storms, not the large infrequent storms
    An infiltration test on the native soils is a good starting test, does the project have:

    - ☐ Native soils infiltration testing
    - ☐ Surface hydraulic conductivity
    - ☐ Subsurface hydraulic conductivity

2. Rainwater Design Criteria (check one)

    - ☐ Rainfall Capture Depth 32 mm
    - ☐ Water Quality- Remove 80 % TSS

    Calculation Method (check one)

    - ☐ Metro Vancouver Stormwater Source Control Design Guidelines 2012 Manual Calculations
    - ☐ Stormwater Models (i.e. XP-SWMM, PC SWMM, etc.)
    - ☐ Other Manual Methods (describe)

    - ☐ Other Municipal Criteria (describe) ______________________
    - ☐ Design Rainfall Capture Depth (mm) ______________________
    - ☐ Inflow Runoff Volume:
      Tributary Area x Design Rainfall Capture Depth (cu.m) ______________________
    - ☐ Capture Volume (sum of 6 values below): ______________________
        - ☐ 24 hour evaporation x soil surface area: ______________________
        - ☐ Volume of source control soil x (field capacity – wilting point): ______________________
        - ☐ Volume of lawn soil x (field capacity – wilting point): ______________________
        - ☐ Volume of rock pit x percentage pore space: ______________________
        - ☐ 24 hour subsurface exfiltration x lawn area: ______________________
        - ☐ 24 hour subsurface exfiltration x rock pit bottom area: ______________________

3. Adequate water quality treatment

    ☐ Yes ☐ No

4. Overflow Drain Heights and Soil Selection

Ponding in surface source controls should be allowed for storm events when rainfall intensity exceeds soil infiltration capacity for the inflow up to the design capture volume.

- ☐ Soil mix infiltration rate:
- ☐ Above Ground Ponding Volume:

  Is ponding volume sufficient? ☐ Yes ☐ No

  Underdrain system required if low permability soils: ☐ Required ☐ Not Required

5. Deciduous Trees

- ☐ Minimize deciduous trees above rain gardens

  Leaves can reduce infiltration rates and interfere with growth of vegetation needed to regenerate soil surface.

  ☐ None/few (preferred) ☐ Some (okay) ☐ Many (not desirable)

6. Infiltrated Water

Where's the infiltrated water going? Will it lift asphalt down slope? Will it end up at a foundation wall? Use trench dams to contain water.

- ☐ Trench dams
- ☐ Underdrain system
- ☐ Overflow system to storm sewers
- ☐ Major flood route

7. Rock Trench/Pit Depths

- ☐ Caution building rock trenches deeper than 0.8 m in low permeable soils
- ☐ Surrounding Native Soil Inundated with Upslope Interflow
  - ☐ Risk of upslope interflow? ________________________________
  - ☐ Rock trench depth: ____________________ (0.8 m or less preferred)

8. Construction Phasing

Contractor Construction Plan

- ☐ Meets the Metro Vancouver Stormwater Source Control Design Guidelines 2012 Construction Staging Considerations

Maintenance Assessment Checklist

CITY OF SURREY

File No.: ___________________________

Project: ____ **Inspector:** _____________________________

Site: ____ **Date/Time:** _____________________________

This is a: ☐ Field Visit ☐ Design Review

1. **Weed Control**
   - If using an amended soil mix developed on site:
     - Germination test to check for viable unwanted seed: ☐ Yes ☐ No
     - Result? _______________
     - If weed seeds are a problem, treat with: ☐ Composting ☐ Mulch
     - Note: mulch should be ground wood not bark, chips, or sawdust
     - Mulch depth: ☐ 50 to 75 mm layer (preferred) ☐ Other:______ mm

2. **Binding Off Of Sand Layer**
   - Sand layer between drain rock and growing medium? ☐ Yes ☐ No
     - If yes, was sand layer exposed to weather (wetting and drying) before placement of growing medium? ☐ Yes ☐ No
     - If yes, sand surface may be damaged – repair required before placement of growing medium? ☐ Yes ☐ No

3. **Builder Management**
   - Education provided on building site management and the impact their activities can have on rain garden areas and other stormwater measures? ☐ Yes ☐ No
   - Builders and trades have adequate access to lots, stockpiling area, etc. ☐ Yes ☐ No
   - No-go areas clearly marked with signage and orange fence around rain garden depression area? ☐ Yes ☐ No
   - Roof gutters not installed before site has been landscaped and rain gardens planted? ☐ Yes ☐ No
   - Building is fully completed prior to removal of sacrificial soil and poly and planting of rain garden ☐ Yes ☐ No
   - Soils on the lot tilled and scarified prior to placing the finishing layer of growing medium? ☐ Yes ☐ No

9. **Maintenance Responsibility**
   - Two to three year warranty period required when developer (public areas) and builder (on-lot) will be responsible for maintenance of rain gardens? ☐ Yes ☐ No
   - Plan in place for watering (automatic or manual) until plantings established? ☐ Yes ☐ No
   - Plant and soil maintenance and weed control planned for twice annually, spring and fall? ☐ Yes ☐ No

     Which of the following options are being used for ongoing maintenance?

     ☐ Restrictive covenant.

     ☐ City staff responsibility.

     ☐ Local area improvement agreement amongst homeowners.

     ☐ Other? Describe: ______________________________________

9. **Road Maintenance Issues**
   - Snow storage areas designated? ☐Yes ☐No
   - Street sweeping program in place? ☐Yes ☐No
   - Regular inspections for sheet flow impediments or concentrated flow damage? ☐Yes ☐No
   - Expected lifespan for topsoil and planting replacement (years)? _____________

10. Performance Monitoring and Warranty Period

- Will post-construction continuous flow, rainfall and water quality monitoring be required? (This is the best way of measuring, but can be very expensive.) ☐Yes ☐No
- Observations that indicate poor performance (should not be observed):
- Mud forming in rain garden? ☐Yes ☐No
- Standing water after a 24 hour storm? ☐Yes ☐No
- Vegetation wall forming at the interface with the flat panel curb? ☐Yes ☐No
- Excessive sediment accumulation (above planned)? ☐Yes ☐No
- Concentrated flows or flow damage? ☐Yes ☐No
- Clogged or submerged overflow? ☐Yes ☐No